Monte Carlo simulation of fast ion generated by ICRF based on orbit following in real coordinates in large helical device

R. Seki, T. Seki, K. Y. Watanabe, H. Kasahara K. Saito S. Kamio and T. Mutoh.
[1] *National Institute for Fusion Science,322-6 Oroshi-cho, Toki 509-5292, Japan*

1. Introduction

In the Large helical device (LHD), we can maintain a long time discharge with electron density, n_e~$1x10^{19}m^{-3}$, for more than one hour by the ICRF minority ion heating [1]. To achieve the discharge with higher ne by the ICRF heating, the optimization of the operating method is under developing because the tau_E in LHD increases with n_e.

In the ICRF minority ion heating, the ICRF wave mainly heats the minority ions near the resonance layer and the absorbed power of the minority ions is transferred to bulk plasma through collisions. Thus, it is necessary to investigate the efficiency on the power transferred from the minority ions to bulk plasmas in addition to evaluation of the ICRF electric field distribution and its damping rate for the evaluation of the heating efficiency of bulk plasmas by the ICRF wave.

A conventional approach to evaluate the efficiency on the power transferred from the minority ions to bulk plasmas in the LHD uses the Monte-Carlo code, and evaluates the distribution function and the heating power profile of minority fast ions [2]. The above approach needs large calculation resources. In finding the optimized heating conditions like the wave frequency, the density and the temperature, the above approach is not adequate because these analyses require the larger calculation resources. In this paper, we propose to evaluate an index of the efficiency on the power transferred from the minority ions to bulk plasmas. And we develop a code where models of behaviours of ICRF fast ion are minimally adopted for saving a time, and show results by the code.

2. Proposal of index and models in developed code.

Figure 1 shows the outline of the developed code in addition to a conventional approach to evaluate the heating efficiency of bulk plasmas for ICRF minority ion heating. The conventional approach is roughly broken-down into two parts as follows: 1) evaluation of the ICRF electric field distribution by solving the electromagnetic wave equations. 2) evaluation of a velocity distribution function of minority ion and a transferred power from minority ions to bulk plasma.

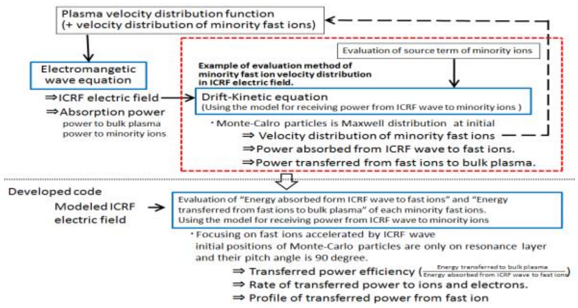

Fig. 1. outline of the developed code and the usual analysis of ICRF minority ion heating

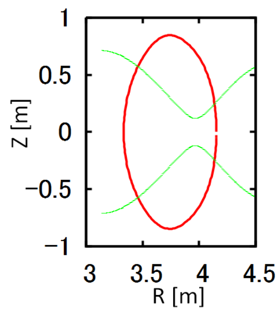

Fig 2. ICRF resonance layer (start point).

In a 1) part of the developed code, electromagnetic wave equations are not solved for saving the time, and this code uses the wave field model where ICRF electric field is uniformly distributed in a tenth of torus (half-helical pitch) on the assumption that the ICRF electric field exist only in region in the front of an ICRF antenna. In the 2) part, in order to evaluate only the efficiency on the transferred power from minority fast ions to bulk plasma, "an energy absorbed from the ICRF wave to minority fast ions" and "an energy transferred from the minority fast ions to bulk plasma" of each minority fast ions are calculated. Particularly in the developed code, only minority fast ions accelerated by ICRF wave are focused. As the model of their fast ions, their initial points are installed on the resonance layer on the vertically elongated poloidal plane shown in Fig. 2 and the initial pitch angle and the initial energy is assumed to be 90 degree and 10 keV.

In the developed code, based on the above models, minority fast ions are traced until they are lost with taking collisions and accelerations due to the ICRF electric field into account. The orbits of each fast ion are traced by using the guiding centre equations. Since the acceleration term due to ICRF electric field is not included in the guiding centre equations, the model of acceleration of fast ions due to the ICRF electric field are required in the code. In this code, a model [2] where the fast ions are accelerated in a direction perpendicular to field line on the resonance layer are used for clarifying effects of position and shape of a resonance layer on the fast ions behaviour. In a collision with bulk plasma, the collision operator [3] which includes a pitch angle scatter and energy relaxation are adopted.

3. Heating efficiency and maximum energy of ICRF fast ions

Using the developed code, we evaluate the efficiency on the transferred power from ICRF minority fast ions to bulk plasma in the LHD ICRF plasma which consists of the helium (major ion), the hydrogen (minority ions) and electrons. Here, a magnetic configuration is assumed to be vacuum magnetic field (magnetic axis = 3.6 m, field strength 2.75 T) which is used by typically ICRF discharge. In the bulk plasma, the plasma consisted of helium ion and electron is assumed and the profile of the plasma temperature and density is uniform for clarifying the dependences on the efficiency.

Initially, the dependence of the strength of the wave field model on the transfer power efficiency to bulk plasma and the maximum energy of minority fast ions is investigated (Fig 3). Here, the transfer power efficiency to bulk plasma defines "an average energy transferred from minority fast ions to bulk plasma through a collision" over "an average energy absorbed from the ICRF wave to the fast ions". The maximum energy of fast ions is the average value of the maximum energy of each fast ion. In the Fig. 3, the electron density is 10^{19} $m^{-3}$and the electron and ion temperatures are 1 keV, which is a typical parameter in the ICRF discharge of LHD. In Fig. 3, the maximum energy of fast ion becomes large with increase in the strength of the wave field model and then the heating efficiency decreases. In the low strength of the wave field model, the transferred power to ion is more than that to electron because the maximum energy is less than the critical energy. In this regime, the transfer power efficiency to bulk plasma is about 0.7. On the other hand, in the high strength case, the main component of the transferred power is electron because the maximum energy of fast ion is high. The transfer power efficiency is less than 0.5.

Figure 4 shows the profile of the transfer power in the low and high strength of the wave field model. In the low strength case (Fig. 4 (a)), although absorbed power from ICRF wave

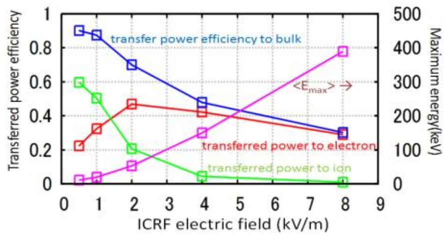

Fig. 3. ICRF electri field dependence on transfer rate.

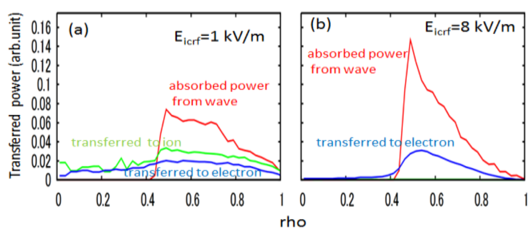

Fig. 4. profile of transfer energy in low (1 kv/m) and high (8 kV/m) strength of ICRF electric field.

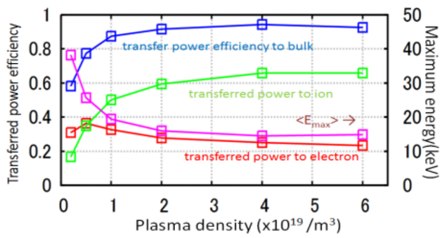

Fig. 5. Plasmas density dependence on transfer rate.

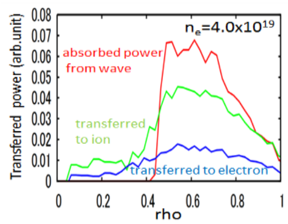

Fig. 6. profile of transfer energy in high density case.

is only in rho > 0.4, there is the transferred power from magnetic axis (rho = 0) to LCRF (rho = 1) and the profiles are flat.

This difference between profiles of transferred power and the absorbed power is caused by changing orbits due to pitch angle scatter before fast ions are lost or slowing down. In the low strength case, the pitch angle scatter time is short since the energy of fast ion is less than the critical energy. On the other hand, in the high strength case (Fig. 3(b)), the peak of the transferred power to electron is close to that of the absorbed power and the transferred power profile is similar to the absorbed power profile because the fast ions are lost before the change in the orbit due to pitch angle scatter.

Next, the plasma density dependence on the transferred power efficiency to bulk plasma and the maximum energy of fast ions is shown in Fig. 5. In this calculation, the strength of the wave field model is 1 kV/m and the temperatures are 1 keV. In Fig. 5, it is found that the maximum energy of fast ions decrease with increase in the plasma density. In the high density case, the transferred power efficiency to bulk plasma is about 0.9. Figure 6 shows the transferred power profile in the high density case. From Fig. 6, the transferred power profile to ion is close to the profile of the absorbed power from ICRF wave.

5. Summary

In order to optimize the transferred power from ICRF fast ions to bulk plasma, we proposal an index of the transferred power rate, and develop a code, where models of behaviours of ICRF fast ion are minimally adopted from the view point to save a calculation time. On the transferred power index from ICRF minority ion to bulk plasma in the ICRF discharge, we obtain the following results. In the cases with the low electric field in the wave field model or high collision frequency, the transferred power to bulk ions is more than that to electrons, and the index of the transferred power becomes high. In the either cases with the low or high collision frequencies, the profile of transferred power has the peak close to that of the absorbed power from ICRF wave to the fast ions. In the regime between high and low density cases, the profile becomes flat in the radial direction including near magnetic axis region.

Reference

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