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Study of toroidal flow generation by the ICRF minority heating in the Alcator C-Mod plasma

Alcator C-Mod プラズマにおける ICRF 少数イオン加熱時のトロイダル流駆動のシミュレーション研究

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The toroidal flow generation by the ICRF minority heating is investigated in the Alcator C-Mod plasma applying GNET code, in which the drift kinetic equation is solved in 5D phase-space. It is found that a co-directional toroidal flow is generated outside of the RF wave power absorption region and that the dominant part of toroidal flow does not depend on the sign of $k_\parallel$. The averaged toroidal flow velocity reaches about 30% of central ion thermal velocity ($P_{ICRF} \sim 1.7$MW). When we change the sign of the toroidal current we obtain a reversal of the toroidal flow velocity, which is consistent with the experimental observations. We show that the toroidal precession motion of energetic tail ions accelerated by the ICRF heating plays an important role in generating the averaged troidal flow. We also compare with the experimental results about the RF resonance location and plasma parameter dependencies.

1 Introduction

Important role of the plasma flow and its shear in the transport improvement is suggested by many experimental observations, e.g. H-mode transition, ITB formation, RWM suppression. In a future reactor the driving of the plasma flow by NBI heating is not efficient and other driving method is required. The spontaneous toroidal flow has been observed during ICRF heating with no direct momentum input in JET[1], Alcator C-Mod[3] and etc. Many theoretical studies have been done. However, further study is necessary to make clear the generating mechanism of spontaneous toroidal flow during ICRF heating.

In this paper we study the toroidal flow generation by the ICRF heating using GNET code[5, 6, 7], which can solve a linearized drift kinetic equation for energetic ions including complicated behavior of trapped particles in 5-D phase space. The obtained steady state distribution of energetic minority ions is analyzed and the radial profile of the toroidal flow is evaluated. In the simulation we assume a tokamak plasma similar to the Alcator C-Mod plasma ($R = 0.67$m, $r \sim 0.21$m, $B_t \sim 5.5$T).

2 Simulation Model

In order to study the ICRF minority heating including finite orbit effect we have developed a global simulation code, GNET[4, 5], which can solve a linearized drift kinetic equation for energetic minority ions, $f_{\min}$, including complicated behavior of trapped particles in 5-D phase space

$$\begin{aligned}\frac{\partial f_{\min}}{\partial t} + (v_\parallel + v_D)\cdot\nabla f_{\min} + \boldsymbol{a}\cdot\nabla\boldsymbol{v} f_{\min} \\ -C(f_{\min}) - Q_{\rm ICRF}(f_{\min}) - L_{\rm particle} &= S_{\rm particle}\end{aligned} \quad (1)$$

where $C(f_{\min})$ and $Q_{\rm ICRF}(f_{\min})$ are the linear Coulomb Collision operator and the ICRF heating term. $S_{\rm particle}$ is the particle source term by ionization of neutral particle and the radial profile of the source is evaluated using AURORA code. The particle sink (loss) term, L_{particle}, consists of two parts; one is the loss by the charge exchange loss assuming the same neutral particle profile as the source term calculation and the other is the loss by the orbit loss escaping outside of outermost flux surface.

Using GNET code we study the toroidal shear flow generation by ICRF minority heating in the Alcator C-Mod Plasma. The resonant magnetic field strength B_{res} is set to be 5.1T and the location of the resonance in the minor radius, r, is about $r/a = 0.3$.

3 Simulation Results

We perform the simulation using GNET code until we obtain a steady state distribution of energetic minority ions solving Eq. (2). We assume the following plasma parameters; $n_{e0} \sim 8 \times 10^{19}\mathrm{m}^{-3}$, $T_0 \sim 3.2$keV and B_0=5.4T. The amplitude of RF electric field, E_0^+, is set to 4.0kV/m. The parallel wave number, $k_{\|}$, is assumed to be $|k_{\|}| = 5\mathrm{m}^{-1}$ and the perpendicular wave number is $k_{\perp} = 50\mathrm{m}^{-1}$.

We can see a broader profile of the toroidal flux in Fig. 1. The flux value at the peak position ($r/a \sim 0.7$) is similar with that of the local heating case[5] and the averaged velocity is about 30% of ion thermal velocity at the plasma center. The heating power is 1.7MW.

Figure 2 shows the contour of the flux surface averaged velocity space distribution, $\ln f_{min}$, of the minority ion at the $r/a = 0.75$. We can see a strong asymmetry in the parallel velocity direction. This asymmetry enlarges in the radial region $r/a \sim 0.75$. Comparing with the local heating case[5] it is found that the asymmetry start rather higher velocity in the broad heating case. This would be related to the RF power absorption also occur in the region $r/a > 0.5$ in the broad heating case.

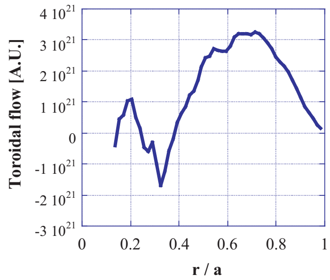

Figure 1: *Radial profile of flux averaged toroidal flow.*

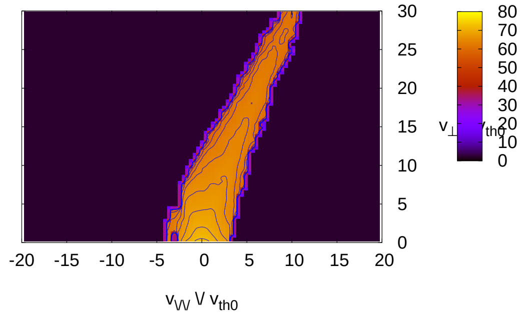

Figure 2: *Contour of the flux surface averaged velocity space distribution,* $\ln f_{min}$*, of the minority ion at the radial regions;* $r/a = 0.75$ *in the broad heating case.*

References

[1] L-G. Eriksson, Plasma Phys. Control. Fusion 39 (1997) 27.

[2] M. P. Brown, and K. Austin, *Appl. Phys. Letters* **85**, 2503–2504 (2000).

[3] J.E. Rice et al., Nucl. Fusion 45 (2005) 251.

[4] T. Ohkawa, Phys. Plasmas **12** (2005) 094506.

[5] S. Murakami, *et al.*, Proc. 23rd IAEAFusion Energy Conference, **THW/P4-03** (2010).

[6] S. Murakami, et al., Nucl. Fusion **40** (2000) 693.

[7] S. Murakami, et al., Nucl. Fusion **46** (2006) S425.