8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Kinetic behavior of supra-thermal electrons by electron cyclotron heating in toroidal plasmas

S. Murakami, Y. Ishida and Y. Yamamoto

[1] Department of Nuclear Engineering, Kyoto University
e-mail (speaker): murakami@nucleng.kyoto-u.ac.jp

Electron cyclotron heating (ECH) generates convection from a low-energy region to a high-energy region in the velocity space, producing a non-Maxwellian plasma with supra-thermal electrons. The behavior of this non-Maxwellian plasma by ECH is complex and generates various physical phenomena that cannot seen in Maxwellian plasmas. Kinetic analysis, including drift orbit effects, is necessary to analyze these phenomena.

We study the behavior of ECH supra-thermal electrons and related physics applying the GNET code[1], which can solve a linearized drift kinetic equation for the deviation of the electron distribution function from the Maxwellian distribution, $\delta f = f - f_M$, by ECH in 5-D phase space. The drift kinetic equation for δf is given by

$$\frac{\partial \delta f}{\partial t} + (\vec{v}_d + \vec{v}_{\parallel}) \cdot \frac{\partial \delta f}{\partial \vec{r}} + \dot{\vec{v}} \cdot \frac{\partial \delta f}{\partial \vec{v}} + Q_{RF}(\delta f) - C(\delta f) - L(\delta f) = S^{ql}_{\mathrm{ECH}}$$

where C, L, $\boldsymbol{v}_{/\!/}$, and $\boldsymbol{v}_d$ are the linear collision operator, the electron loss term, the ECH quasi-linear heating term, and the parallel and drift velocities, respectively. S^{ql} and Q_{RF} are the ECH quasi-linear heating term and the ECH nonlinear heating term expressing the acceleration of the supra-thermal electrons by higher harmonic resonances.

In this talk, we will present two topics: first, the toroidal flow generation by ECH in a stellarator, and second, fast electron generation by the multiple resonance heating in a spherical tokamak.

Toroidal flow generation by ECH

Spontaneous flows related to the ECRH heating have been observed in tokamaks and stellarators. ECRH-driven supra-thermal electron flux generates the radial current. Ion radial current cancels the electron one and generates the **j**×**B** torque to bulk plasma. Also, supra-thermal electrons drift in the toroidal direction and generate the collisional torque. We study the **j**×**B** and collisional toroidal torques due to supra-thermal electrons during ECH in LHD and HSX applying GNET code[2,3]. It is found that the **j**×**B** torque related to the supra-thermal electrons plays an essential role in generating toroidal flow in the LHD and HSX plasmas. Figure 1 compares the simulation and experiment results of the toroidal flow with and without ECH. This result suggests the important role of the ECH supra-thermal electrons in the toroidal flow generation in stellarators.

Fast electron and CD by multi-harmonics heating

Fast electrons (E>100keV) and plasma current rump up that cannot be explained by simple EC heating have been observed during ECH in the QUEST spherical tokamak[4]. Experimental results suggest this would be due to the resonant acceleration of ECH supra-thermal electrons by the higher harmonics (third and fourth) resonance heating. However, theoretical verification of the kinetic theory involving fast electron orbits has yet to be carried out.

We study the behavior of ECH fast electrons in QUEST spherical tokamak using GNET code, including the effects of third- and fourth-harmonic resonance heating. We find that supra-thermal electrons generated by the second harmonic ECH are further accelerated by the third and fourth harmonic heating. We also find that the generation of fast electrons by multiple resonance depends on $N_{/\!/}$ and obtain the same order plasma current (up to 100kA). The distribution of fast electrons due to multiple resonances is found to be highly dependent on the RF electric field parameters.

References

[1] S. Murakami, et al., Nuclear Fusion **40** (2000) 693.
[2] Y. Yamamoto, et al., Phys. Plasmas **28** (2021) 102501.
[3] Y. Yamamoto, et al., Nuclear Fusion **62** (2022) 064004 .
[4] T. Onchi, et al., Phys. Plasmas **28** (2021) 022505.

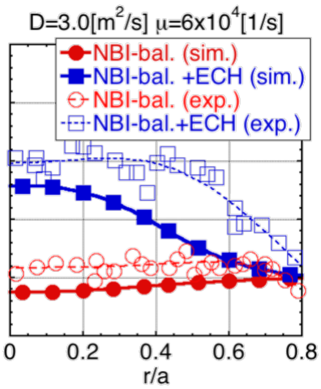

Fig. 1: Comparisons of the simulation and experiment results of the toroidal flow w/wo ECH in LHD.