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原型炉における電子サイクロトロン波電流駆動の複数モードによる最適化

Optimization of Electron Cyclotron Current Drive in DEMO Using Multi Modes

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Non-inductive current drive by electron cyclotron waves in tokamak fusion reactors has various merits such as high power-flux density, high central accessibility, high deposition profile controllability, and reliable power source, gyrotron. The most challenging issue of electron cyclotron current drive (ECCD) is the enhancement of current drive efficiency in order to reduce the circulating power in fusion reactors.

The lower current drive efficiency of ECCD compared with lower-hybrid waves and neutral beam is attributed to the perpendicular acceleration, the circular resonance curve in velocity space due to the relativistic effects, the deviation of acceleration direction from the resonance curve, and the magnetic trapping effects. It is difficult to extract a small number of bulk electrons and continually accelerate them to high velocity by a single mode.

In the present analysis, we consider the possibility of enhancement of ECCD efficiency using multi modes with different frequencies, injection angles, or injection locations. If the multi modes strongly interacts with electrons on a same magnetic surface, electrons can be continually accelerated by optimizing the resonance curve in the bounce-averaged velocity space.

For the present analysis the ray-tracing module TASK/WR and the Fokker-Planck module TASK/FP of the integrated tokamak modeling code TASK are employed. The ray tracing analysis includes the relativistic effects of electron cyclotron resonance and the non-Maxwellian velocity distribution function, and the Fokker-Planck analysis includes the relativistic quasi-linear velocity diffusion and the collisional effect with non-Maxwellian velocity distribution function to keep the momentum and energy conservation.

First the midplane injection is considered. The poloidal and toroidal injection angle dependence of deposition minor radius (Fig.1) and the current drive efficiency (Fig.2) is surveyed for several wave frequencies. Then the target minor radius is fixed, and the contour of quasi-linear diffusion coefficients in velocity space is examined for modes which deposit on the target minor radius with various injection angles and frequencies. Finally, after choosing a mode extracting bulk electrons and modes accelerating the extracted electrons, the Fokker-Planck analysis is carried out to describe the synergetic effects of multi-mode current drive.

Quantitative results are presented, and further optimization procedure will be discussed.

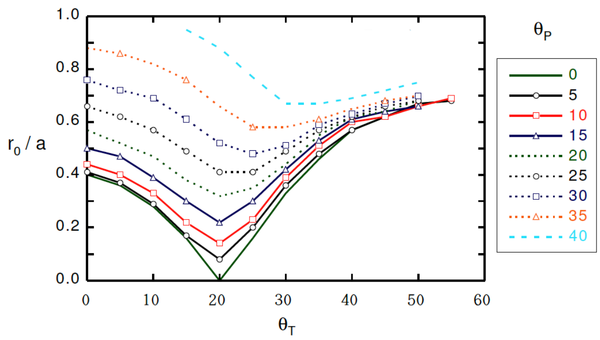

Fig. 1 Injection angle dependence of deposition minor radius

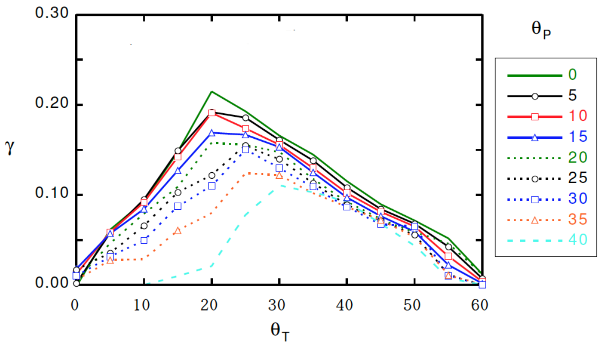

Fig. 2 Injection angle dependence of current drive efficiency

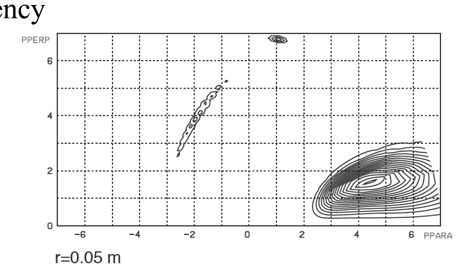

Fig. 3 Example of quasi-linear diffusion coefficient in velocity space