24P039-P

Calculation of Ion Radial Transport in the GAMMA10 A-divertor
GAMMA10 A-divertorにおけるイオンの径方向輸送の計算

Shun Masaki, Isao Katanuma, Shuhei Sato, Kazuto Sekiya and Tsuyoshi Imai
真崎　俊, 片沼伊佐夫，佐藤周平，関谷和人，今井　剛

Plasma Research Center, University of Tsukuba
1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8577, Japan
筑波大学・プラズマ研究センター 〒305-8577　茨城県つくば市天王台 1-1-1

Numerical calculation of ion orbits in the GAMMA10 A-divertor magnetic configuration was carried out. By incorporating Monte Carlo code into the orbit calculation, the effects of Coulomb collision were taken into account. Under anisotropic electrostatic potential, the neoclassical diffusion of ions was enhanced.

1 Introduction

Plasma Research Center, University of Tsukuba is now planning replacement of west anchor cell in the GAMMA10 tandem mirror with an axisymmetric divertor configuration shown in Figure 1. One of the purpose of this plan is the simulation experiment of a divertor in large torus devices, utilizing some existing heating systems. Core plasma with high temperature and density is artificially evacuated to dipole region, where a divertor plate is installed. The electrostatic fluctuation is considered as a way of artificial exhaust and in our investigation we seek anisotropic electrostatic potential which cause efficient evacuation, calculating ion trajectories under the potential. The particle orbit calculation code was to include the effects of Coulomb collision and ions diffused radially under anisotropic electrostatic potential.

Calculation meshes coincide with magnetic surface coordinates and the magnetic field is stored on the mesh points. We calculate the following drift equations using the predictor-corrector method and tracked a guiding center.

$$\begin{aligned}\frac{d\psi}{dt} &= -c\frac{\partial\phi}{\partial\theta} - \frac{c[2(\epsilon-q\phi)-\mu B]}{qB}\frac{\partial B}{\partial\theta}\\ \frac{d\theta}{dt} &= c\frac{\partial\phi}{\partial\psi} + \frac{c[2(\epsilon-q\phi)-\mu B]}{qB}\frac{\partial B}{\partial\psi}\\ \frac{d\zeta}{dt} &= v_\parallel B\end{aligned}$$

Here $\nabla\zeta = \nabla\psi\times\nabla\theta = \boldsymbol{B}$ and $\nabla\psi\cdot\nabla\zeta = \nabla\theta\cdot\nabla\zeta = 0$ are satisfied in the coordinates. ϵ and μ mean total energy and the magnetic moment of a test particle respectively and the other notations are conventional. $\nabla\psi\cdot\nabla\zeta = \nabla\theta\cdot\nabla\zeta = 0$ under the assumption of axisymmetric magnetic field and the normal component of magnetic field line curvature is obtained from the relation

$$\frac{\partial B}{\partial\psi} = \frac{B_z}{rB}\frac{\partial^2 r}{\partial l^2} - \frac{B_r}{rB}\frac{\partial^2 z}{\partial l^2}$$

where, $\partial/\partial l$ is the derivation along a magnetic field line.

Before introducing Coulomb collisional effects, the verification of the Monte Carlo code was done. The linearized Fokker-Planck equation is used on this code and change in velocity due to collisions satisfies the following three equations.

$$\frac{\partial\boldsymbol{u}}{\partial t} = \frac{\boldsymbol{u}}{u}\frac{\mu_\parallel}{\delta t} \tag{1}$$

$$\frac{\partial}{\partial t}\Delta u_\perp^2 = \frac{\sigma_\perp^2}{\delta t} \tag{2}$$

$$\frac{\partial}{\partial t}\Delta u_\parallel^2 = \frac{\sigma_\parallel^2}{\delta t} \tag{3}$$

where,

$$\begin{aligned}\mu_\parallel &= \delta t\sum_\alpha\Big(1+\frac{m_T}{m_\alpha}\Big)\Big[2\sqrt{\frac{a_\alpha}{\pi}}\frac{1}{u}\exp\{-a_\alpha u^2\}\\ &\quad -\frac{1}{u^2}\mathrm{erf}\{\sqrt{a_\alpha}u\}\Big]\Gamma_\alpha\\ \sigma_\parallel^2 &= \frac{2\delta t}{u}\sum_\alpha\Big[-\frac{1}{\sqrt{\pi a_\alpha}}\frac{1}{u}\exp\{-a_\alpha u^2\}\\ &\quad +\frac{1}{2u^2a_\alpha}\mathrm{erf}\{\sqrt{a_\alpha}u\}\Big]\Gamma_\alpha\\ \sigma_\perp^2 &= \frac{2\delta t}{u}\sum_\alpha\Big[\frac{1}{\sqrt{\pi a_\alpha}}\frac{1}{u}\exp\{-a_\alpha u^2\}\\ &\quad \Big\{1-\frac{1}{2u^2a_\alpha}\Big\}\mathrm{erf}\{\sqrt{a_\alpha}u\}\Big]\Gamma_\alpha\end{aligned}$$

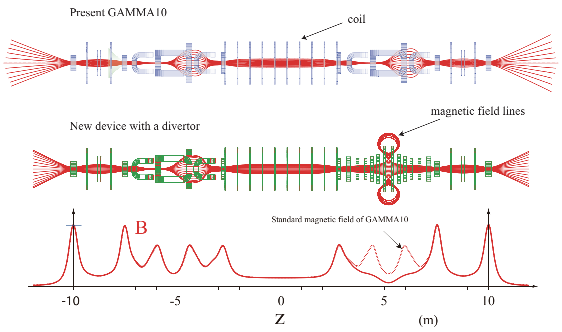

Fig. 1: GAMMA10 A-divertor

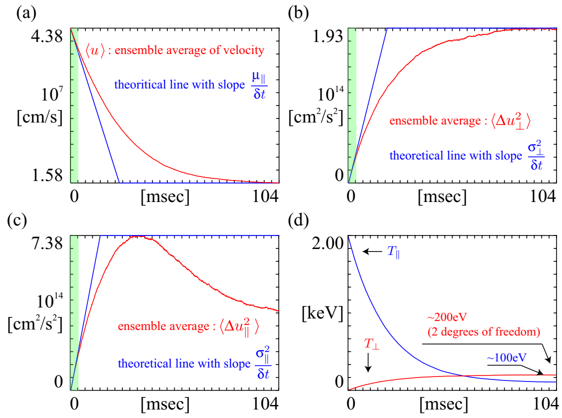

Fig. 2: Time evolution of particle velocity and temperature

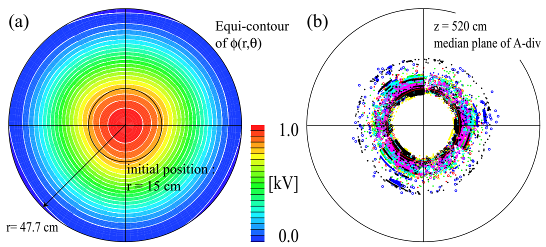

Fig. 3: Electrostatic potential and Poincare map

Here $u_\parallel$ and $u_\perp$ mean respectively parallel and perpendicular components of a velocity vector before collisions. particle velocities after Coulomb collisions is assumed to follow a normal distribution and $\mu_\parallel$, $\sigma_\perp^2$ and $\sigma_\parallel^2$ are its mean and variances (two directions) respectively. Change in velocity is probabilistically calculated by normal random numbers. When particle trajectories are traced, velocity changes calculated by the Monte Carlo method should be added to particle velocities determined in the orbit calculation code, which includes the effects of Coulomb collisions effectively.

2 Calculation Results

As the verification of the Monte Carlo code, a large number of ions with initial energy 1keV collided with field electrons with temperature $T_e = 100\mathrm{eV}$ and density $n = 10^{12}/\mathrm{cm}^3$, excluding field ions. The time evolution of the ensemble average of u, $\Delta u_\perp^2$ and $\Delta u_\parallel^2$ is respectively plotted in the figure 2(a), (b) and (c). The straight line in three figures corresponds to the theoretical value of slowing down and the pitch angle scattering which ions with 1keV receive from this field. It was found that calculation results satisfied equations (1), (2) and (3) because both lines accorded in the linear region of each figures. In addition, figure 2(d) shows that both $T_\parallel$ and $T_\perp$ was relaxed to the field temperature.

Then, the Monte Carlo code was embedded in the particle trajectory calculation code and ions were traced. Figure 3(a) represents a two-dimensional distribution of non-axisymmetric electrostatic potential model, that is, the axisymmetric component of $\phi = 1000\mathrm{V}$ on the z-axis with its perturbation of the mode number m = 3. Here, the model potential is assumed to be constant along a magnetic field line. The orbits of ions were calculated including Coulomb collisional effects under this non-axisymmetric potential. Figure 3(b) is the Poincare map of the median plane of A-divertor. $T_i = 1\mathrm{keV}$, $T_e = 10\mathrm{eV}$ and $n = 10^{12}/\mathrm{cm}^3$ were assumed in the calculation and some of Maxwellian particles with initial mean energy 450eV were plotted in the map. Because ions are deeply trapped in the axisymmetric magnetic divertor, there is no radial diffusion under axisymmetric electrostatic potential, while they diffused radially under non-axisymmetric one. This result represents that total energy ϵ and the magnetic moment μ of test particles were updated by collisions and that the particle trajectory at the median plane of A-div changed from transit orbit which doesn't excurse the initial magnetic surface to banana orbit with a large radial deviation, diffusing radially there.

3 Conclusion

We practiced the verification of Monte Carlo code and it was validated to include Coulomb collision effects in the enough accuracy. The radial diffusion of ions due to Coulomb collision arised in the anisotropic potential.