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The calculations about the Neoclassical diffusion of ions in GAMMA10 A-divertor

GAMMA10 A-divertor 中央ミラー部におけるイオンの新古典拡散に関する計算

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Previously, Monte Carlo simulation was performed to research the Neoclassical transport in GAMMA10 A-divertor. The guiding center approximation of ion orbit and the paraxial approximation of magnetic field are used in the simulation. It was found that the large transport occurs even in the GAMMA10 A-divertor.

1 Introduction

GAMMA10 A-divertor is the remodeling device of GAMMA10. This device is replaced its nonaxisymmetric magnetic field of anchor cell with an axisymmetric divertor configuration. The object of this device is performing divertor simulation experiments of large torus device. Here, predictable consequence is that the magnitude of the neoclassical transport becomes altered due to replacing the configuration. Therefore, this research aims to show quantitative informations of the radial transport in GAMMA10 A-divertor using Monte Carlo method.

2 Calculation model

We omit gyro motion of particle and calculate only drift motion of guiding center. This drift motion is calculated by drift equation. We use the expression

$$\boldsymbol{v} = v_{\parallel}\hat{e}_{\parallel} - \frac{c\nabla\phi \times \mathbf{B}}{B^2} - \frac{mc\left(v_{\perp}^2 + 2v_{\parallel}\right)\nabla B \times \mathbf{B}}{2qB^3} \tag{1}$$

as drift equation. Here, $v_{\parallel}$ is the component along magnetic field line of velocity, $\hat{e}_{\parallel}$ is the unit vector along magnetic field line and $v_{\perp}$ is perpendicular velocity to magnetic field line. Second term of this equation is $\mathbf{E} \times \mathbf{B}$ component and third term is ∇B and curveture drift component. We define (ψ, θ, z) coordinate system, where z axis is chosen along magnetic field line and $\mathbf{B} = \nabla\psi \times \nabla\theta$. $\psi = \int_0^r B_z r dr$ increases toward radius direction and θ is increasing toward azimuthal direction. Besides, paraxial approximation is approved when $|B_x/B_z| \ll 1, |B_y/B_z| \ll 1$ and we assume that energy of the particle ε and magnetic moment μ is conserved. Therefore drift equation is transformed into

$$\frac{d\psi}{dt} = -\left[c\frac{\partial\phi}{\partial\theta} + \frac{c}{q}\left\{2\varepsilon - \mu B - 2q\phi\right\}\kappa_{\psi}\right] \tag{2}$$

$$\frac{d\theta}{dt} = c\frac{\partial\phi}{\partial\psi} + \frac{c}{q}\left\{2\varepsilon - \mu B - 2q\phi\right\}\kappa_{\theta} \tag{3}$$

$$\frac{dz}{dt} = \pm\left[\frac{2}{m}\left\{\varepsilon - \mu B - q\phi\right\}\right]^{\frac{1}{2}} \tag{4}$$

Here, $\kappa_{\psi}, \kappa_{\theta}$ are the component of curvature. The expressions of curvature are

$$\kappa_{\theta}(\psi, \theta, z) = \hat{\kappa}_{\theta}\psi \sin 2\theta \tag{5}$$

$$\kappa_{\psi}(\psi, \theta, z) = \frac{1}{2}\hat{\kappa}_{\psi}(z) - \frac{1}{2}\hat{\kappa}_{\theta}(z)\cos 2\theta \tag{6}$$

where,

$$\hat{\kappa}_{\theta}(z) = -\frac{r_0^2}{2\psi}\left[\sigma(z)\frac{d^2\sigma(z)}{dz^2} - \tau(z)\frac{d^2\tau(z)}{dz^2}\right] \tag{7}$$

$$\hat{\kappa}_{\psi}(z) = \frac{r_0^2}{2\psi}\left[\sigma(z)\frac{d^2\sigma(z)}{dz^2} + \tau(z)\frac{d^2\tau(z)}{dz^2}\right] \tag{8}$$

and the expressions of magnetic field line are

$$x(\psi, \theta, z) = \sigma(z)r_0\cos\theta \tag{9}$$

$$y(\psi, \theta, z) = \tau(z)r_0\sin\theta \tag{10}$$

Monte Calro method was used to calculate effects of coulomb collision. A basic equation of collision is Fokker-Planck equation.

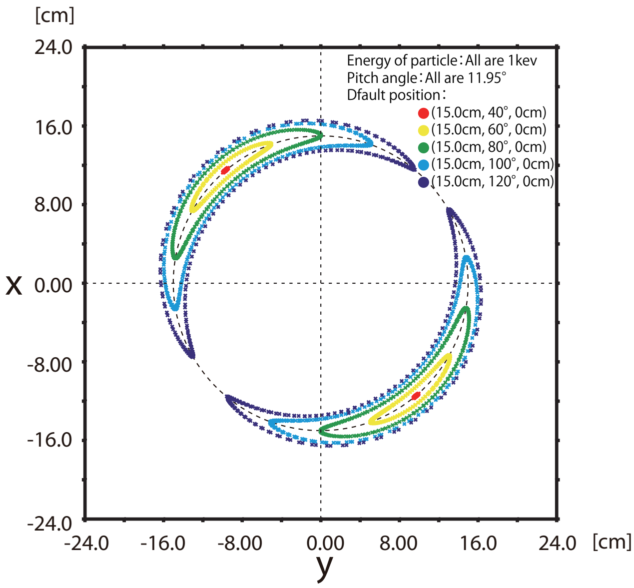

Fig. 1: Banana orbits when initial azimuthal positions are $40° - 120°$.

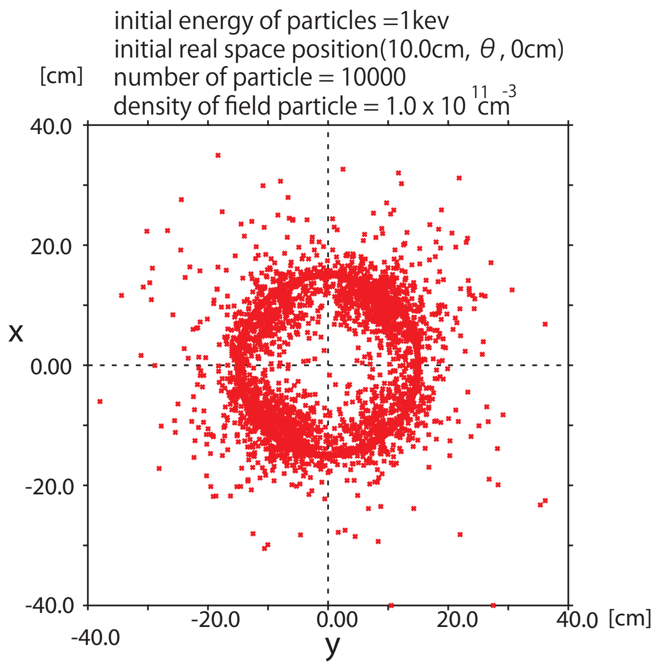

Fig. 2: Including collision effects. Faster diffusion occurred in the position of banana orbit than other nonresonant particles.

3 Calculation result and Discussion

We define Poincaré plot of a record of intersection points of a particle orbit on x-y plane when a particle passes through $z = 0$. Potential is assumed as $\phi = 300\,(1 - \psi/\psi_0)$ [V/cm], ψ_0 is ψ at $r = 18$cm and r is distance from z axis. Circular orbits which encircle z–axis were confirmed at most parameters of ε and μ. However, at some particular parameters of ε, μ, we found the particles drawing banana orbits. If particle energy was 1keV, the banana orbits were existing while pitch angle $11.95° \pm 2.45°$ at $z = 0$ and when we changed initial azimuthal positions, distortion magnitude of banana orbits are altered . Figure 1 shows each banana orbit when initial azimuthal positions are changed. Even if radial initial position was changed, the banana orbits still exist.

Figure 2 shows the particle positions mapped at $z = 0$ when $t = 32.310$ms, where collision effects are included. The particles around the positions of banana orbits begin to diffuse fast rate. This data indicates that the banana orbits have an influence on the diffusion.

Figure 3 plots diffusion coefficient as a function of collision frequency. Note, collision frequency depends on the density of field particles.

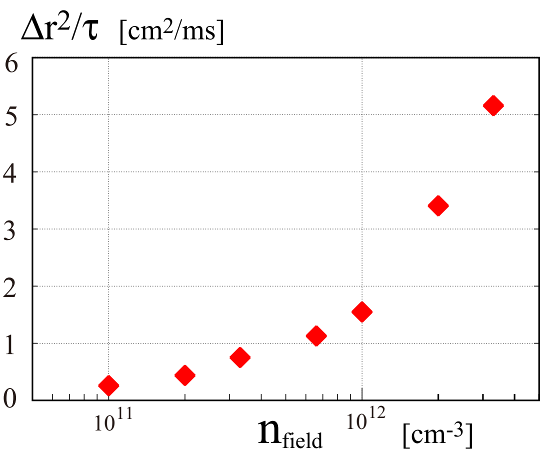

Fig. 3: Diffusion coefficient

4 Summary

We confirmed the existence of the banana orbits and those banana orbits cause a fast rate diffusion of ions. The diffusion coefficient changes with the density of field particles.

We would like to calculate detailed profile of diffusion coefficient for our future work.