Effects of fluctuating magnetic field on particle transport in a field-reversed configuration

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Effects of fluctuating magnetic field in a Field-Reversed Configuration (FRC) have investigated with the aid of single particle tracing routine. The canonical angular momentum of a plasma particle ($P_\theta = mv_\theta r + q\Psi$; $\Psi > 0$ inside the separatrix) varies temporally in a fluctuating magnetic field, although it is a constant of motion in axisymmetric FRC. Observation shows the sign of average time derivative of the canonical angular momentum is negative. This suggests the accessible region of a confined particle shifts gradually toward the separatrix and particles will be lost away to the open field region.

1. Introduction

Particle transport mechanism in a Field-Reversed Configuration (FRC) is an ambiguous but important issue for the scaling of confinement time and future reactor study of FRC with advanced fuel [1]. Main mechanism of particle transport has not been determined as yet because of difficulties in diagnostic technique to measure the pulsing events. Since the obtainable data are restricted by an experimental approach, it is very important to investigate the cross-field transport in an FRC by numerical method. In the history of transport study of FRC, lower hybrid drift instability has believed to be the dominant process [2], however, it is disproved by Carlson’s experiment [3]. Recently the combination of radial and open-field transport is also found to be possible to modify the scaling of gross confinement time [4]. One of the authors proposed the adiabaticity breaking process near X-points [5] enhances the end loss rate, which also increases the density gradient and resultant radial flow around the separatrix. Though the open-field transport is possible to affect the gross confinement time, we consider that the radial transport is still more dominant in the FRC confinement mechanisms. In the present paper, the fluctuating magnetic field is examined as the transport mechanism, and investigated the dependence of it on the temporal change of the canonical angular momentum, which results in the radial drift of particles.

2. Model and Calculation Procedure

In order to show the radial transport of particles, we observe the single particle motion inside the separatrix of axisymmetric FRC whose equilibrium is written in the form:

$$\Psi = \frac{1}{2} B_W r^2 \left(1 - \frac{r^2}{r_s^2} - \frac{z^2}{(l_s / s)^2} \right) ,$$

where B_w, r_s and l_s is the magnetic field on the midplane, separatrix, the separatrix radius and length, respectively. The parameters of those are chosen from the conceptual D-^{3}He/FRC reactor "ARTEMIS-L". This equilibrium is known as Hill's vortex model. We have calculated the single particle motion in this equilibrium model with fluctuating magnetic field and without the electric field, which is given as

$$B_1 = \delta B \sin(2\pi ft),$$

where δB and f denote the amplitude and the frequency of a fluctuating magnetic field. The fluctuation takes place synchronously in all components of magnetic field described by cylindrical coordinates. Without the fluctuation, the particles in a steady state and an axisymmetric FRC are able to move in the *accessible region* and never be lost in a case this region is closed against the wall and the mirror throat. Figure 1 shows the accessible region for 100-keV deuteron with the canonical angular momentum P_θ are 0.05 and 0.1. The values are normalized by $qB_w r_s^2$. Particles with smaller P_θ are confined in the region closer to the separatrix. Thus, the mechanism that is able to reduce P_θ contributes the radial particle transport. We calculate 5000 different particles that start on the different position chosen randomly, where the magnetic field is minimum along the field line in the accessible region. A set of particles is prepared to have the same kinetic energy E and the same canonical angular momentum P_θ initially so as to find the dependences of those on the transport coefficients. Data are obtained at t=100/ω_c where ω_c denotes the gyration frequency at the separatrix on the midplane, and they are averaged statistically.

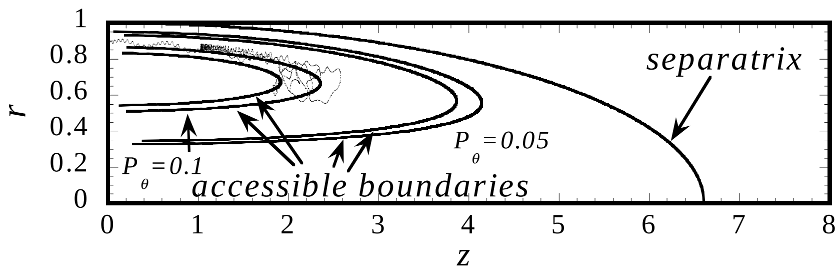

Fig. 1. Accessible region for the particles with the canonical angular momentum P_θ=0.05 and 0.1. The separatrix of Hill's vortex FRC and sample orbit of particle with P_θ=0.1 in the fluctuating magnetic field; $\delta B/B_w$=0.1 and $2\pi f$=0.1ω_c, are also presented.

3. Results and Discussion

We trace the particle orbit numerically and present the evolution of P_θ in Fig. 2 in which three sample cases are drawn. Frequencies of fluctuation are given by 0.5ω_c, 0.1ω_c and 0.01ω_c. We can easily notice that the lower frequency of fluctuation affects significantly the temporal change of P_θ. Note that fluctuations reduce P_θ in all cases eventually. This implies that particles in the fluctuating magnetic field drift radially according to the accessible region shown in Fig. 1. Setting the identical

P_θ of 5000 particles, we traced the orbits of them and output P_θ at t=100/ω_c. In Fig. 3, the histogram of P_θ is drawn for the particles with initial P_θ given as 0.01. Most particles are found to have the smaller P_θ than initial one. The ensemble average of the time derivative of P_θ depends on the guiding center of particles. In order to find this dependence, we calculate several sets of the particles with the same P_θ, and present this in Fig. 4. Solid line is drawn to fit biquadratic curve with respect to P_θ. The value of P_θ for the particles near the magnetic axis deviates from the initial one because of the local resonance between gyrating motion and the fluctuation. Rough estimate gives the particle confinement time approximately 50 μsec in a case of $\delta B/B_w$=0.1 and $2\pi f$ =0.1 ω_c. To find the scaling of the particle confinement time with respect to the amplitude and the frequency is the subject for future study.

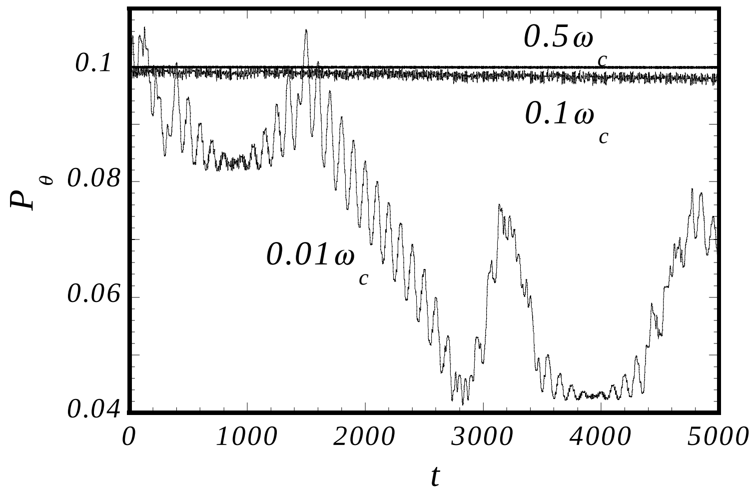

Fig. 2. The temporal change of P_θ for $\delta B/B_w$=0.1. The frequencies of fluctuation $2\pi f$ are 0.5 ω_c, 0.1 ω_c and 0.01ω_c, respectively. Initial values P_θ are all 0.1.

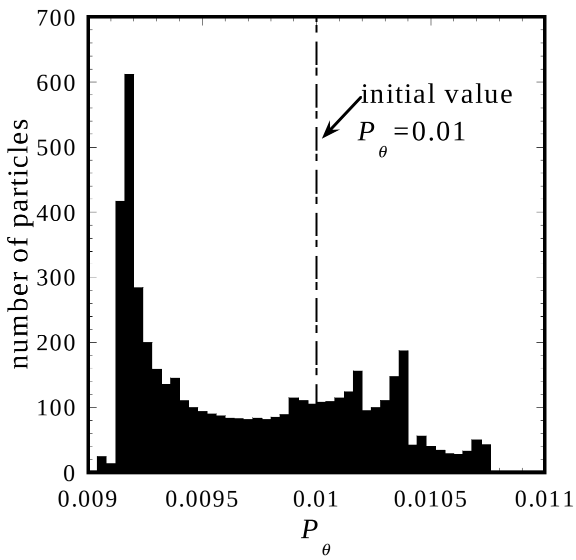

Fig. 3. The histogram of P_θ at t=100/ ω_c. The canonical angular momentum is set to be 0.01 initially. Amplitude and frequency of fluctuation are $\delta B/B_w$=0.1 and $2\pi f$ =0.1 ω_c, respectively.

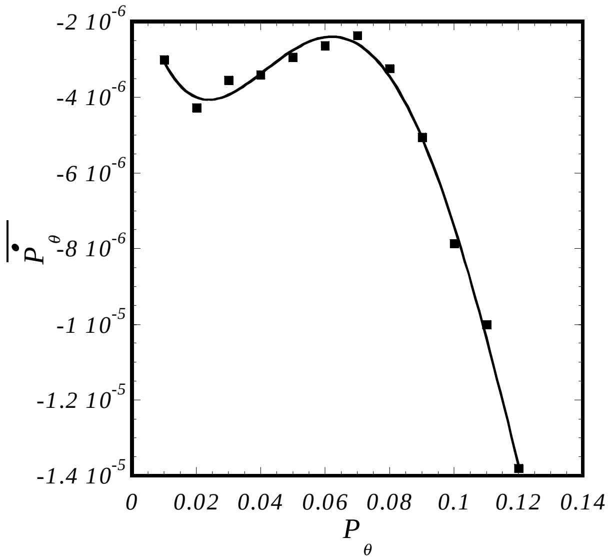

Fig. 4. The dependence of ensemble average of time derivative of P_θ on P_θ for 100-keV deuteron.

4. Conclusions

Effects of fluctuating magnetic field in an FRC have investigated with use of single particle tracing routine. The canonical angular momentum of a plasma particle reduces in a fluctuating magnetic field in many cases, which suggests the accessible region of a confined particle drifts gradually toward the separatrix and particles will be lost away to the open field region. The particle confinement time is 50 μsec at a rough estimate in the present case. To find the scaling of it with respect to the amplitude and frequency is the subject for future study.

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