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Particle Simulation of Blob Propagation in Non-Uniform grad-*B* Plasmas
磁場勾配が非一様なプラズマにおけるブロブ伝播の粒子シミュレーション

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The dynamics of plasma blob propagation in non-uniform grad-B plasmas are investigated with a three-dimensional electrostatic plasma particle simulation code. In simulations, it is found that potential and particle flow structures are different from those shown in our previous studies in which grad-B is assumed to be uniform in the toroidal and poloidal directions. Furthermore, it is shown that propagation manners of blobs in non-uniform grad-B plasmas are also distinct. These properties depend on the initial blob location in the toroidal direction.

1. Introduction

Recently, it was reported that the evidence of non-diffusive (i.e., convective) plasma transport from the edge of core plasma to the first wall in magnetic confinement fusion devices. Such a transport is believed to be brought by intermittent filamentary coherent plasma structures “blobs” in scrape-off layer (SOL) [1]. Many theoretical and numerical studies about blob dynamics have been performed on the basis of two-dimensional reduced fluid models [1]. However, closure of parallel current and kinetic effects, such as sheath formation between a SOL plasma and a divertor plate and velocity difference between electrons and ions, are treated under some assumptions and parameterization in such kind of macroscopic model. Thus, we have developed a three-dimensional electrostatic plasma particle simulation code with particle absorbing boundaries [2] and studied kinetic dynamics on the blob propagation [3].

In our previous studies, we assumed that grad-B is uniform in the toroidal and poloidal directions. In SOL plasmas of real magnetic confinement devices, however, the direction of grad-B is different between the inside and the outside of torus. In this study, we have investigated the blob kinetic dynamics in the system where grad-B is spatially non-uniform (that is, also varies in the toroidal direction). We observe potential and particle flow structures different from those shown in our previous studies. Thus, it is found that propagation properties of blobs in non-uniform grad-B plasmas are also distinct. These properties depend on the initial blob location in the toroidal direction.

2. Simulation Configuration

We use a three-dimensional electrostatic particle simulation code with full particle dynamics to investigate blob propagation in non-uniform grad-B plasmas. The x, y, and z directions correspond to the counter radial direction, the poloidal direction, and the toroidal direction. The external magnetic field $\boldsymbol{B}$ does not have the y component. The x and z components are given as

$$\frac{B_x}{B_0} = -\frac{L_x}{D}\left[\ln\left(\frac{3}{2}-\frac{x}{2L_x}\right)+\ln\left(\frac{3-\alpha}{2}-\frac{x}{2L_x}\right) - \ln\left(\frac{5}{4}\right)-\ln\left(\frac{5}{4}-\frac{\alpha}{2}\right)\right]\mathrm{sech}^2\left(\frac{z-L_z/2}{D}\right) \quad (1),$$

$$\frac{B_z}{B_0} = \frac{2L_x}{3L_x - x}\left[\frac{1}{2}-\tanh\left(\frac{z-L_z/2}{D}\right)\right] + \frac{2L_x}{(3-\alpha)L_x + x}\left[\frac{1}{2}+\tanh\left(\frac{z-L_z/2}{D}\right)\right] \quad (2).$$

Thus, the direction of grad-B at z = 0 is opposite to that at $z = L_z$ and B_x at $x = L_x$ / 2 is zero as shown in Fig. 1. Here, B_0 is the magnetic field strength at $x = L_x$ where L_x, L_y, and L_z are the system lengths in the each direction, and D is set as $D = L_x$ / 16. Particle absorbing boundaries corresponding to divertor plates are placed in the both ends of z axis. A particle absorbing boundary corresponding to the first wall is also placed at x = 0. In the y direction, periodic boundary condition is applied. The system size L_x x

$L_y \times L_z$ is 64 Δ x 64 Δ x 512 Δ where Δ is the grid spacing. The blob is initially located as a column along the ambient magnetic field at around $(x, y) = (L_x / 2, L_y / 2)$. The effective width of the blob in the poloidal cross-section is $\delta_b = 4\,\Delta$. The ion-to-electron mass ratio is $m_i / m_e = 100$. The initial ion-to-electron temperature ratio is $T_i / T_e = 0.25$

3. Simulation Results

3.1 *Case I*

The coefficient α, the external magnetic field strength Ω_i / ω_{pi}, the grid spacing Δ, and the time step Δt are set as $\alpha = 1$, $\Omega_i / \omega_{pi} = 1$, $\Delta = 0.97\,\rho_s$, and $\Delta t = 2.42 \times 10^{-3}\,\Omega_i^{-1}$, respectively. Here, Ω_i is the cyclotron frequency at $(x, z) = (L_x, 0)$, ω_{pi} is the ion plasma frequency in the background plasma, ρ_s is defined as $\rho_s = c_s / \Omega_i$, and c_s is the ion acoustic speed. The blob is initially elongated between $z = 0$ and L_z. When $\alpha = 1$, B_z at $x = L_x / 2$ does not vary in the z direction as shown in Fig. 1 (a). In this case, the blob almost stays at initial position (see Fig. 2 (a)).

3.2 *Case II*

The coefficient α, the external magnetic field strength, the grid spacing, and the time step are set as $\alpha = 2$, $\Omega_i / \omega_{pi} = 0.5$, $\Delta = 0.48\,\rho_s$, and $\Delta t = 1.21 \times 10^{-3}\,\Omega_i^{-1}$, respectively. The blob is initially elongated between $z = 0$ and L_z. When $\alpha = 2$, $B_z(z = 0) < B_z(z = L_z)$ except at $x = L_x$ where B_z is constant in the z direction as shown in Fig. 1 (b). In this case, the blob is torn across the magnetic field line (see Fig. 2 (b)).

3.2 *Case III*

The coefficient α and the external magnetic field strength are the same as those of Case II. The grid spacing and the time step are set as $\Delta = 0.49\,\rho_s$ and $\Delta t = 1.23 \times 10^{-3}\,\Omega_i^{-1}$. The blob is initially localized between $z = 0$ and $L_z / 2$ as shown in Fig. 1 (c). In this case, the blob propagates to the first wall ordinarily (see Fig. 2 (c)).

4. Summary

We have investigated the dynamics of blob propagation in non-uniform grad-B plasmas with the three-dimensional electrostatic plasma particle simulation code. Since non-uniform grad-B affects the particle flows and the potential structure in the blob, the manner of blob propagation in non-uniform grad-B plasma is distinct from that in uniform plasma.

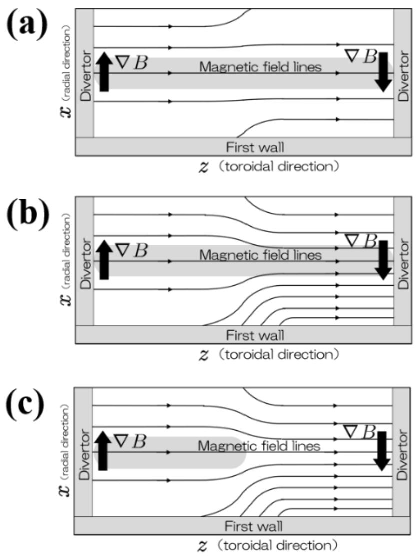

Fig. 1. Magnetic field configurations of Cases I (panel (a)), II (panel (b)), and III (panel (c)).

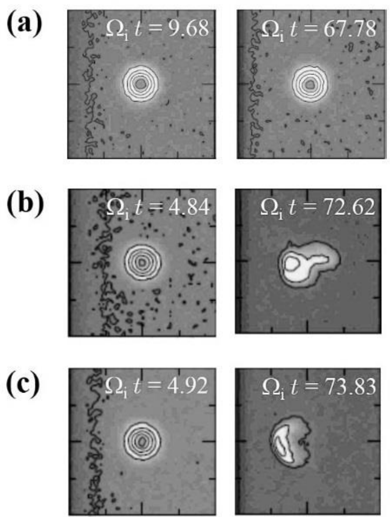

Fig. 2. Electron density distributions on the x-y plane at $z = L_z / 4$. Panels (a), (b), and (c) show those of Cases I, II, and III, respectively.

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