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Propagation of Resistive Interchange Modes
抵抗性インターチェンジモードの伝播

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The propagation of resistive interchange modes is investigated by four field model simulation. The resistive interchange modes generate magnetic islands in the nonlinear phase. The electron diamagnetic velocity decreases due to the flattening of the pressure inside the magnetic islands and the ExB zonal flow generates near the rational surface. Although the linear mode propagation velocity is smaller than the electron fluid velocity, the propagation velocity of the saturated magnetic islands is close to the electron fluid velocity in the nonlinear phase when the width of the magnetic island is larger than a critical width.

1. Introduction

In helical plasmas like Large Helical Device (LHD), suppression of pressure gradient driven MHD instabilities is a crucial issue. The MHD instabilities are experimentally observed with the real frequency. In LHD, it was found that resistive interchange modes rotate with the electron fluid velocity[1]. The propagation of the modes is strongly affected by diamagnetic effects that are two-fluid effect. For previous studies of the MHD instabilities in LHD plasmas[2-4], three field model or one fluid full MHD model were mainly used. These models do not include two-fluid effect so that the diamagnetic rotation can not be studied. In order to clarify the mechanism which determines the mode propagation, simulations of the resistive interchange modes are carried out by using four filed model which includes the two-fluid effect.

2. Numerical Model

In this study, the following normalized four field model is used in slab plasmas.

$$\frac{\partial U}{\partial t} = [U,\phi] + [\psi, J] + 2[p, \Omega_h]$$
$$- \frac{\delta}{2}\left\{[p,U] + [\phi, \nabla_\perp^2 p] + \nabla_\perp^2[p,\phi]\right\} + \nu_\perp \nabla_\perp^2\{U + \delta\nabla_\perp^2(p - p_{eq})\}$$
$$\frac{\partial \psi}{\partial t} = [\psi, \phi - \delta p] + \eta(J - J_{eq})$$
$$\frac{\partial p}{\partial t} = [p,\phi] + 2\beta\delta[\psi, J] + \beta[\psi, v] + 2\beta[\Omega_h, \phi - \delta p] + \chi\nabla_\perp^2(p - p_{eq})$$
$$\frac{\partial v}{\partial t} = [v,\phi] + [\psi, p] + \nu_\parallel \nabla_\perp{}^2 v$$
$$J = \nabla_\perp{}^2\psi, U = \nabla_\perp{}^2\phi$$
$$[f,g] = \frac{\partial f}{\partial x}\frac{\partial g}{\partial y} - \frac{\partial f}{\partial y}\frac{\partial g}{\partial x}$$

U, ψ, p and v are vorticity, magnetic flux, electron pressure and parallel velocity, respectively. The two-fluid effect (ion skin depth) δ is defined as $\delta=(2\Omega\tau_A)^{-1}$, where Ω and τ_A are the ion cyclororon frequency and the Alfven time, respectively. In this study, δ changes from 0.02 to 0.08. In our simulation code, Second order finite difference method is used in the x direction and a fix boundary condition is used at x=0 and x=1, where perturbations set to be zero. With respect to y, a periodic condition is used and Fourier mode expansion method is used in the y direction. For the time integration, second order predictor-corrector method is used.

3. Linear Analysis

For initial equilibrium profiles, the magnetic field and pressure profiles are assumed to be hyperbolic tangent profiles. The rational surface is located at x=0.5. Equilibrium current is set to be zero and the curvature term Ω_h is finite. Figure 1 shows the dependence of the linear growth rate on the mode number. The results obtained by three field model[6] is also plotted. Since the interchange mode is pressure driven modes, the linear growth rate increases with the mode number. When the two-fluid effect is included, the linear growth rates are significantly reduced. Since the dissipative coefficients such as the viscosity and the thermal diffusivity are finite ($\chi=\nu=\nu_\parallel=10^{-6}$), the higher modes are perfectly stabilized. The mode propagates in the electron diamagnetic direction. The propagation velocity is smaller than the electron diamagnetic velocity which is same as the electron fluid velocity in the linear phase. Since the perturbed magnetic flux is zero at the rational surface, the resistive interchange mode does not generate magnetic islands in the linear phase.

4. Nonlinear Evolution

In the initial nonlinear phase, magnetic islands are generated by the resistive interchange modes. After that, the magnetic islands coalesce into a large magnetic island. The saturated width magnetic island decreases as the two fluid effect becomes larger. Figure 2 shows the relation between the width of the magnetic island and the propagation velocity for various δ. In Fig.2, the ExB velocity, the electron diamagnetic velocity and the electron fluid velocity (=electron diamagnetic velocity + ExB velocity) at the rational surface are also plotted. The electron diamagnetic drift velocity decreases as the island width increases since the pressure gradient decreases inside the magnetic island. The ExB zonal flow is generated and its direction is the ion diamagnetic drift direction. When the width of the magnetic island is small, the island remains to propagate in the electron diamagnetic direction and the propagation velocity of the magnetic island is smaller than the electron fluid velocity. As the width of the magnetic island increases, the propagation velocity of islands decreases since the electron diamagnetic drift velocity becomes small.
When the width of the magnetic island is larger than some critical width, the magnetic island propagates into the ion diamagnetic drift direction. The propagation velocity of the magnetic island is close to the electron fluid velocity for large magnetic island.

5. Summary

The propagation velocity of the resistive interchange modes is investigated by four field model simulation. In the linear phase, the propagation of the mode is smaller than the electron fluid velocity. In the nonlinear phase, the resistive interchange mode generates magnetic islands. Then the electron diamagnetic velocity decreases and the zonal flow (ExB flow) generates in the ion diamagnetic drift direction. As the width of the magnetic island increases, the propagation velocity of the magnetic island becomes close to the electron fluid velocity. It suggests that existence of the magnetic island is important role to determine the propagation of the resistive interchange modes in the nonlinear phase.

References

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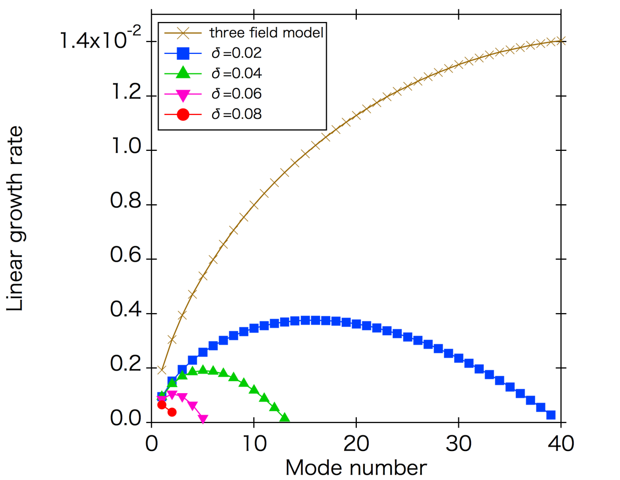

Fig.1. Dependence of the linear growth rate on the mode number.

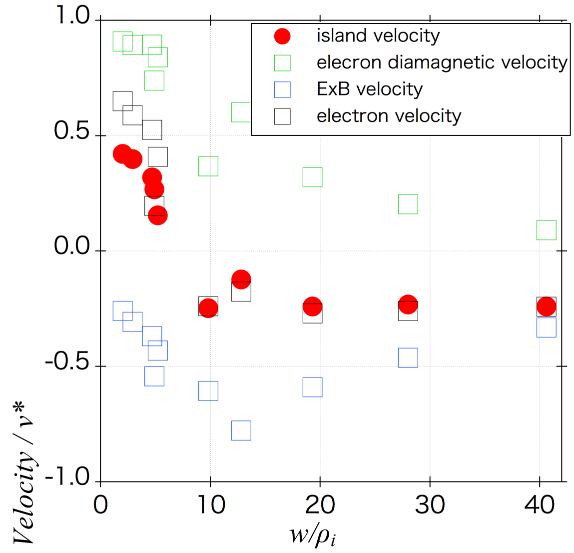

Fig.2. Dependence of propagation velocity of magnetic island on the width. The ExB flow velocity, electron diamagnetic velocity and the electron fluid velocity at the rational surface are also plotted. The holizontal axis is the island width normalized by the ion Lamor radius.