Magnetic island evolution in hot ion plasmas with/without turbulence

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Abstract

Effects of finite ion temperature on magnetic island evolution are investigated by numerically solving a set of reduced two-fluid equations. In the absence of ion temperature gradient, it is found that polarization current is destabilizing and drives the island growth when the island width is larger than 5 times the ion Larmor radius. This is in contrast to the fact that the polarization current is generally stabilizing in cold ion plasmas. In the presence of ion temperature gradient, it is found that ion temperature gradient mode (ITG) driven turbulence enhances the drag force acting on magnetic island and the polarization current becomes destabilizing even when the island width is smaller than 5 times of the ion Larmor radius and when the polarization current is otherwise stabilizing.

1. Introduction

Magnetic islands appear in magnetically confined torus plasmas, and they limit achievable plasma beta and sometimes cause disruptions in large scale tokamaks such as ITER [1]. Tearing instabilities are caused by spontaneous magnetic reconnection that may occur at a rational surface in a sheared magnetic configuration in a magnetically confined plasma. According to Magnetohydrodynamic (MHD) theory, the stability parameter of tearing instabilities determines the instability threshold and thus the formation of magnetic islands. An equilibrium is stable (unstable) against tearing instabilities when this stability parameter is negative (positive). Tearing instabilities are current driven instabilities, and thus are most unstable for long-wavelength perturbation. In modern tokamaks magnetic islands appear in high beta discharges, even if the linear analysis tells that tearing modes are stable. This nonlinear instability is caused by perturbation of the bootstrap current and is called neoclassical tearing modes (NTMs) [2]. The excitation threshold of NTM is mainly determined by the boot strap current perturbation and the polarization current in the modified Rutherford equation.

The excitation of NTM is thought to be affected by polarization current, which is caused by flow around the separatrix of magnetic island. In this work we investigate the effect of ion temperature. In Sec. 2 we describe our model. In Sec. 3 we present effects of uniform ion temperature on the polarization current. In Sec. 4 we consider the effect of turbulence on the polarization current.

2. Simulation model

We consider a two-dimensional slab-plasma which is uniform along an ambient magnetic field. The model used here is a reduced set of two-fluid equations in the cartesian coordinates [3, 4]. We assume that magnetic island evolution is in the Rutherford regime and the dynamics which determines the flow around the island is much faster than the evolution of island, so that the dynamics is electrostatic. The model consists of equations that describe temporal evolutions of the electrostatic potential, the density, the parallel ion velocity, and the ion temperature. The equations include not only electron diamagnetism in Ohm's law but also ion diamagnetism in the vorticity equation. Simulations are carried out in the island fixed frame, where the width and poloidal location of magnetic island do not change. Uniform ExB flow is applied to the plasma, and the drive as well as the drag force acting on the island are calculated as a function of the externally applied flow velocity. This work extends previous work [5, 6] by including finite ion temperature effects.

3. Island in uniform ion temperature plasma (without ITG turbulence)

In finite ion plasmas, magnetic islands propagate toward the electron diamagnetic direction for island of width up to 10 times the ion Larmor radius. As the island width increases, its propagation velocity slows down much faster than in a cold in plasma. The polarization current is almost an order of magnitude larger in hot ion than in cold ion plasmas. This is because the flow shear around the separatrix of magnetic island is much larger. When the island width is larger than 5 times the ion Larmor radius, the polarization current is positive, i.e. it drives magnetic island growth. The destabilization is the largest when the island width is 10 times the Larmor radius.

4. Island in ITG turbulence

In this section we consider the effect of ITG turbulence on the polarization current. Turbulent electron flow appears within the island separatrix, while turbulent ion flow spreads outside of the separatrix. The zonal flow induced by the ITG turbulence is very strong and plays the central role in determining the island propagation velocity. Zonal flow produced by micro-turbulence generally affects dynamics of macro-MHD instability [7]. It is found that the turbulent flow enhances the drag force acting on the island. The effective viscosity increases ten times approximately. The ion fluid inertia, which determines the ion flow velocity shear around the island separatrix, is responsible for the production of the polarization current. The polarization current term is destabilizing in the presence of ITG turbulence, even when the island width is smaller than 5 times the ion Larmor radius and the polarization current is stabilizing in the absence of turbulence.

5. Summary

We have investigated the impact of finite ion temperature on the magnetic island evolution by means of two-fluid simulations in slab geometry. Even when the ion temperature profile is uniform and ITG is stable, the island propagation velocity and polarization current is significantly different from those in cold ion plasmas. The island propagates in the electron diamagnetic direction and the speed of propagation decreases faster than that with cold ions. The polarization current is destabilizing when the island width is larger than 5 times the ion Larmor radius. In the presence of turbulence driven ion temperature gradient, the turbulence significantly enhances the force acting on the island, because turbulent diffusion of momentum across the separatrix is large. The polarization current destabilizes the magnetic island in the presence of ITG turbulence, even when it is stabilizing in the absence of turbulence. In addition, the polarization current with turbulence is an order of magnitude larger than that without turbulence. The destabilizing effects of finite ion temperature with/without ITG turbulence on magnetic island may explain the spontaneous neoclassical tearing modes that have been observed to occur in the absence of a triggering event such as a sawtooth crash.

References

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