25C06

Effects of Micro-Turbulence on Excitation of NTM
新古典テアリングモード励起への微視的乱流の影響

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Effects of micro-turbulence on the excitation of neoclassical tearing modes (NTMs) are investigated by numerically solving a set of reduced two-fluid equations. It is found that the kinetic ballooning mode driven turbulence produces long-wavelength magnetic islands on q=1.5 rational surface, even if the profile is stable against tearing instabilities. The island width is several times the ion Larmor radius, and this suggests that the turbulence can produce the seed island of NTM. It is also found that ion temperature gradient mode driven turbulence enhances the drag force acting on magnetic island and can make polarization current effect in the Rutherford equation destabilize.

1. Introduction

Magnetic islands are ubiquitous in magnetically confined torus plasmas, and they limit achievable plasma beta and sometimes cause disruptions in large scale tokamaks such as ITER. Tearing instabilities are caused by spontaneous magnetic reconnection that may occur at a rational surface in a sheared magnetic configuration, such as a current sheet in a magnetically confined plasma. According to Magnetohydrodynamic (MHD) theory, the Δ' 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 bootstrap current and is called neoclassical tearing modes (NTMs) [1, 2].

The growth of NTM requires a threshold called seed magnetic island, and there are two issues regarding the seed island. One is the formation process of the seed island. It is considered that the other MHD activities such as sawtooth or ELM cause the seed island. The other issue is the evaluation of the threshold, i.e. the width of the seed-island. In this work we investigate the effect of micro-turbulence on the two issues, because turbulence can be driven by pressure-gradient instabilities around rational surfaces. In Sec. 2 we consider the effect of turbulence on the formation of seed magnetic islands. In Sec. 3 we consider the effect of turbulence on the threshold.

2. Formation of seed-island by turbulence

In this section we will show that long-wavelength magnetic islands are produced by micro-turbulence driven by kinetic ballooning instabilities, even if the profile is stable against tearing instabilities. The island formation is examined by three-dimensional simulation codes in torus plasma [3]. The island formation by ion temperature gradient instabilities (ITG) in a plasma slab was reported in our previous work [4]. Figure 1 shows color map of electrostatic potential and the equi-contours of helical magnetic flux for m/n=3/2 on a poloidal section. The turbulent flow gives rise to magnetic reconnection at the q=3/2 rational surface. The equi-contours of helical magnetic flux clearly show that long-wavelength magnetic islands are formed at the rational surface of q=3/2. The stability parameter of (m,n)=(3,2) mode is approximately -2. Hence, we see that long-wavelength magnetic islands can exist even if the tearing mode is stable. The wavelength of the magnetic island is much longer than the ion Larmor radius and is the same order as the minor radius, and the width is several times the Larmor radius. The shape of the magnetic islands is different from that of a typical tearing mode because the turbulent flow causes fluctuations in the magnetic field.

3. Effect of turbulence on the threshold

The excitation threshold of NTM is determined by the bootstrap current term and the polarization current term in the modified Rutherford equation. In this section we consider the effect of ITG turbulence on the polarization current term by means of numerical simulations of a reduced set of two-fluid equations in slab geometry. 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 island, 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. Figure 2 shows that turbulent electron flow appears within the island separatrix, while turbulent ion flow spreads outside of the separatrix. 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 turbulence.

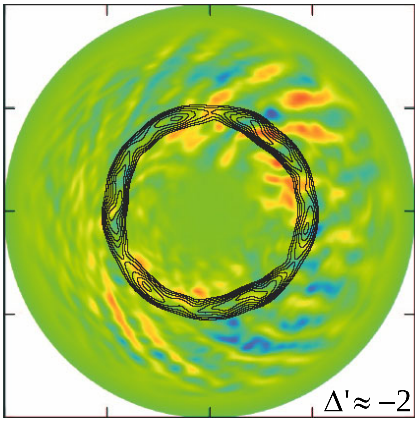

Fig.1. Electrostatic potential profile and equi-contours of helical flux. Turbulence driven kinetic ballooning modes is strong at the bad curvature region. Coherent magnetic islands appear at the q=1.5 rational surface.

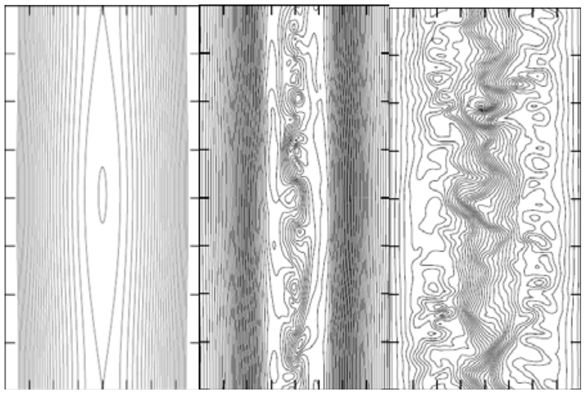

Fig.2. Magnetic surfaces (left), electron flow stream lines (center) and ion flow stream lines (right).

4. Summary

We have carried out numerical simulations of a reduced set of two-fluid equations in torus plasmas. We have found that kinetic ballooning driven turbulence causes coherent magnetic islands at the q=1.5 rational surface, even if the stability parameter of tearing modes is negative. The width of magnetic island is several times of ion Larmor radius. The typical width of the required seed-island is evaluated to be several times ion Larmor radius by using experimental data [2]. Thus, the turbulence can produce seed magnetic islands and explain the “spontaneous” NTMs that have been observed to occur in the absence of a triggering event such as a sawtooth crash. We have also found that ITG driven turbulence enhances the drag force acting on magnetic island, and can make the polarization current term destabilizing.

Acknowledgments

This work is supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology, Grant No. 23561003.

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