§6. Intrinsic Propagation of Magnetic Island with Finite Width

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A new type of tearing mode has been observed in recent low collisional plasmas even when a tearing mode is classically stable. The metastable tearing mode is called the neoclassical tearing mode (NTM), which limits the achievable beta in high performance discharges. In theoretically understanding the NTM, the modified Rutherford equation is used as a model equation describing evolution of island width, which consists bootstrap and polarization terms as the minimum. According to conventional models, the NTM is unstable when the island propagates toward the electron diamagnetic drift direction[1),2)], which is showing importance of determination of the propagation direction. However, more accurate analyses are necessary because the models are valid in the limit of cold ions. And ion motion along the magnetic field line is also needed in a consistent treatment.

Here, the propagation direction is investigated in two dimensional slab geometry based on a reduced two fluid model which includes both effects of ion and electron diamagnetic drifts as well as the ion parallel motion[3)]. For numerical calculations, a finite-differential method is applied to the radial direction and the periodic boundary condition is imposed for the poloidal direction. The number of grids in a simulation box is chosen to 400×20, and temporal evolution is calculated by using a predictor-corrector method with each time step size $\Delta t = 10^{-3}$. All of the calculations are performed under the condition with the viscosity $\nu = 10^{-6} \sim 10^{-4}$, the electric resistivity $\eta = 10^{-4}$, the parallel viscosity $D_v = 10^{-4}$, and the temperature ratio $\tau = 1$. Note that the stability parameter Δ' is positive for only $m = 1$ mode and other modes are linearly stable. From now, we discuss the rotation frequency of $m = 1$ mode.

Temporal evolutions of island poloidal velocity, the electron diamagnetic velocity, the zonal flow velocity, and the sum of the electron diamagnetic and zonal flow velocities are shown in Fig.1. The viscosity is chosen to $\nu = 5 \times 10^{-6}$. Note that each velocity is averaged over the flux surface. We found that pressure is totally flattened and zonal flow is generated inside the island in the saturation regime whereas residual pressure is observed in conventional models, indicating the importance of the parallel ion motion in determining the propagation direction precisely.

Fig.2 shows temporal evolutions of kinetic energy of each poloidal mode for two viscosity cases (a) $\nu = 5 \times 10^{-6}$ and (b) $\nu = 3 \times 10^{-5}$. The growth rate of zonal flow is twice larger than that of the m=1 mode, indicating that the zonal flow is mainly generated from the $m = 1$ mode. As seen in Fig.2(a), the zonal flow finally becomes the most dominant mode in the saturation regime. On the contrary, we can observe that in case (b)

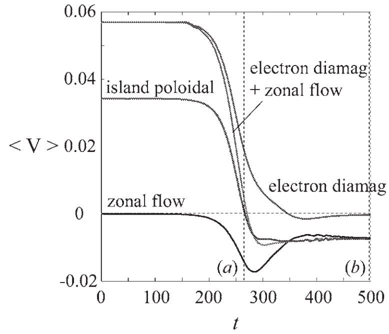

Fig. 1: Temporal evolutions of island poloidal velocity and drift velocities.

the zonal flow energy decreases due to the viscous damp and zonal flow energy is same or small compared to energy of other modes. Plotted in Fig.3 are radial structures of zonal flow potential inside the island for two viscosity cases (a) $\nu = 5 \times 10^{-6}$ and (b) $\nu = 3 \times 10^{-5}$. Two different temporal snapshots $t = 250$ (early phase of nonlinear regime) and $t = 550$ (saturation regime) are plotted for each case. The dotted line indicates the separatrix at given time. It is found that the radial mode structure turns over its function form in the saturation regime in case (b), whereas the mode structure keeps monotonically decreasing function through temporal evolution in case (a). This is attributed to deformation of mode structure of zonal flow by other modes, as expected in Fig.2(b).

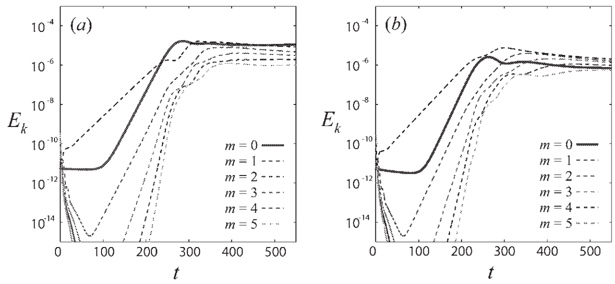

Fig. 2: Temporal evolutions of kinetic energy of each poloidal mode for two different viscosity cases (a) $\nu = 5 \times 10^{-6}$ and (b) $\nu = 3 \times 10^{-5}$.

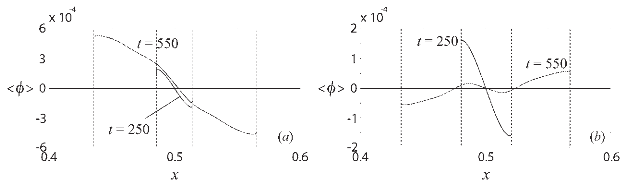

Fig. 3: The radial structures of zonal flow potential inside the island for two viscosity cases (a) $\nu = 5 \times 10^{-6}$ and (b) $\nu = 3 \times 10^{-5}$ at different time $t = 250$ and $t = 550$.

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3) Hazeltine, R. D. *et al* : Phys. Fluids 28 (1985) 2466.