§28. Zonal Flow Dynamics in the Double Tearing Mode with Antisymmetric Shear Flows

Li, J.Q., Mao, A. (Dalian Univ. of Technology),
Imadera, K., Kishimoto, Y. (Kyoto Univ.)

Double tearing mode (DTM) may be excited in the reversed magnetic shear configuration which is beneficial to the improvement of confinement performance. Theoretical investigations show that the DTM consists of two unstable eigen states corresponding to the anti-symmetric (namely, X-point to O-point) or the symmetric (namely, O-point against O-point) island structure on two rational surfaces. The former is usually more unstable. For the DTM instability, it has been observed that the shear flows between two rational surfaces can reduce the island growth through decoupling two islands. On the other hand, it has been realized that zonal flows are of importance in suppressing the cross-field turbulent transport through reducing the radial coherence length of the turbulent eddies, leading to the spontaneous formation of the transport barriers and the L-H transition. However, the zonal flows do not occur in a pure MHD fluctuation such as the resistive tearing mode or the DTMs due to the symmetry of their MHD structures. In this work, we report the zonal flow dynamics in the DTM in the presence of antisymmetric shear flows.

Simulations are carried out using reduced 2-field resistive MHD model in a configuration with double current sheets with distance $\delta x = 0.8$.[1] An initial value code is applied. The antisymmmetric shear flow is expressed as $\upsilon_{eq} = \upsilon_0 \tanh(\kappa x)$. From the eigenmode value analyses of the DTM,[2] a critical flow amplitude υ_c was observed, below which two unstable DTMs with even and odd parity for the perturbations are static but tend to propagate in opposite direction with the same growth rate above it. Nonlinear simulations show that the zonal flow oscillation occurs in linear growth phase or in the so-called Rutherfold regime, which depends on the shear flow amplitude. Different oscillation mechanism has been identified.

For weak shear flow with $\upsilon_0 < \upsilon_c$, remarkably, a prominent oscillation of the zonal potential energy is observed in the Rutherford regime when the zonal component grows to be comparable with the dominant component, as shown in Fig.1, while the evolution of the zonal magnetic energy does not show any oscillation behavior. The oscillation mechanism is elucidated based on the nonlinear interaction between the islands and the shear flows as follows, which is referred to as I-type ZF oscillation. During the ZF oscillation, the amplitudes of the zonal flows around two current sheets are alternatively varying so that the total shear flows acting on the islands are modified by the zonal flows. Such oscillation behavior is akin to that in a simple gravity pendulum, in which the energy is transferred between the magnetic fluctuations and the kinetic flows. The magnetic pressure enhanced by the island distortion provides a restoring force.

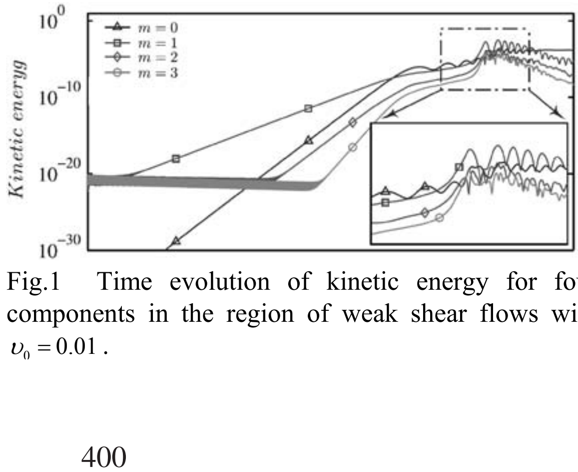

Fig.1 Time evolution of kinetic energy for four components in the region of weak shear flows with $\upsilon_0 = 0.01$.

For the medium shear flow with $\upsilon_0 > \upsilon_c$ but below the KH stability threshold, though the universal evolution processes of the DTM are generally revealed, different from the case without or with weak shear flows $\upsilon_0 < \upsilon_c$, an oscillatory growth of the zonal potential energy accompanying with zonal magnetic energy is observed even in linear growing phase, as shown by the blue curve in Fig.2. Furthermore, the oscillation feature of the zonal potential energy looks to depend on the amplitude of shear flows. For the flow slightly larger than υ_c, on one hand, the zonal potential oscillation in the linear phase behaves alternatively with both long and short periods. On the other hand, the oscillation in the linear phase also connects to the I-type ZF oscillation in the Rutherford regime. However, as the flow amplitude increases, such as, the zonal potential oscillation becomes regular and continue to sustain in the Rutherford regime as a residual part, rather than the I-type ZF oscillation. Based on conventional three-wave mode coupling or a modulation process pumped by two different DTM eigen modes, it is identified that the generation mechanism of oscillatory ZFs originates from the competition between self-coupling of each DTM eigen mode and the cross-coupling between two propagating DTM eigen modes. This kind of ZF oscillation is referred to as C-type ZF oscillation.

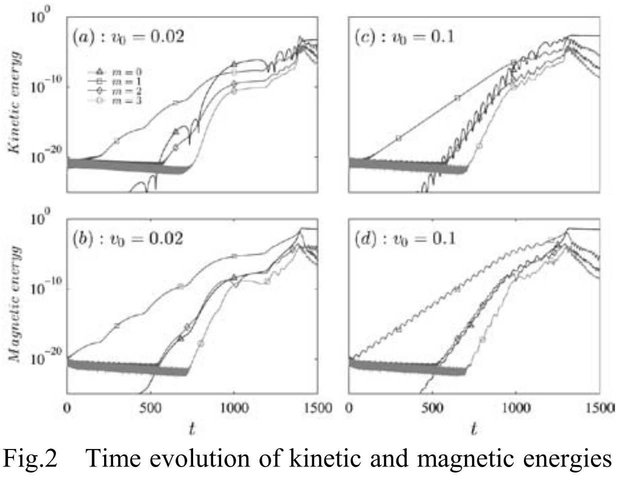

Fig.2 Time evolution of kinetic and magnetic energies for four components for medium shear flows.

1) P. L. Pritchett, et al., Phys. Fluids **23**, (1980)1368.
2) A. Mao, et al., Phys. Plasmas 20, (2013)022114.