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Nonlinear Simulation of Tearing Mode and m=1 Kink Mode Based on Kinetic RMHD Model

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Abstract In this paper, we investigate dynamics of sawtooth oscillation and neoclassical tearing modes based on kinetic RMHD model to elucidate the mechanism of nonlinear excitation of them, putting an emphasis on interaction with microscopic and transport processes. Various routes of excitation of MHD modes by turbulence are demonstrated. It is shown that research on the hierarchical interaction between turbulence and MHD is important in Tokamak physics.

1. Introduction

Magnetized plasmas are nonuniform and far from thermal equilibrium. Consequently, various kinds of bifurcations could appear followed by an abrupt change of the topological structure of the magnetic field. Sawtooth oscillation and neoclassical tearing modes(NTM) are those examples. In this paper, we investigate dynamics of those modes based on kinetic RMHD model to elucidate the mechanism of nonlinear excitation of them, putting an emphasis on interaction with microscopic and transport processes. Various routes of excitation of MHD modes by turbulence are demonstrated.

2. Nonlinear Simulation of Tearing Mode Based on Neoclassical RMHD Model

NTM is investigated using the four-field neoclassical MHD equations, where the fluctuating ion parallel flow and ion neoclassical viscosity are taken into account[1]. It is found that NTM is stabilized by ion neoclassical viscosity, ion and electron diamagnetic effect in banana regime even if $\Delta' > 0$. If one of them is not kept in the system, then the mode is unstable. Figure 1 shows the dependence of the growth rate on the collisionality. The solid curve indicates the four-filed model, the dotted curve, the three-field model and the dashed curve, four-filed model without ion neoclassical viscosity. We also perform nonlinear simulation of tearing mode(TM) with single-helicity in the collisional regime $\nu_e = 100\tau_{Ap}^{-1}$.

Collisional drift wave is simultaneously solved with tearing mode. Figure 2 shows the time evolution of Fourier components of electromagnetic energy. Figure 3 shows the time evolution of corresponding power spectrum. Initially, collisional drift waves with high m/n mode are unstable and inverse cascade occurs in spectral space. The nonlinear growth rate of the 2/1-mode in initial phase is larger than the linear growth rate by an order of magnitude. In final phase, m/n=0,0 and 2/1 modes are dominant in the system and 2/1 island is clearly observed. Nonlinear excitation of TM due to collisional drift wave is firstly shown in this paper. This is important as a novel mechanism for the onset of NTM. We expected NTM is nonlinearly excited if the drift Alfven-ITG turbulence is incorporated in the system. We report the nonlinear excitation of TM and NTM with multi-helicity modes by electromagnetic turbulence.

3. Nonlinear Simulation of Internal Kink Mode Based on Kinetic MHD Model

The nonlinear study of the $m/n = 1/1$ kinetic internal kink (KIK) mode based on the cylindrical gyro-reduced-MHD (GRM) model [2], revealed that (1) vortices are generated by the Kelvin-Helmholtz (K-H) like instability due to the sheared poloidal flow and that (2) the KIK is stabilized once but destabilized again when the vortices damps. In the following study, we found that this process repeat several times; quasi-limit-cycle exists due to the coupling of the vortices and the KIK mode. The effects of mesoscale vortex generation are missing in the standard sawtooth crash theory but may have significant consequence because the vortex generation adds another root of energy-sink, which is closely related to the subtle nonlinear stability of the KIK mode. The toroidal effect is most interesting because of generation and transport of vortices with different helicities. Hence, we made the kinetic FAR (KFAR) by adding kinetic terms in FAR (toroidal resistive MHD code). The linear benchmark test in the cylindrical limit verified good agreement between the KFAR and the GRM codes. Results of nonlinear calculations will be presented. Though the compressibility, which is not so far included in KFAR, is important for the linear growth rate, the nonlinear behavior simulated by KFAR is less influenced by it.

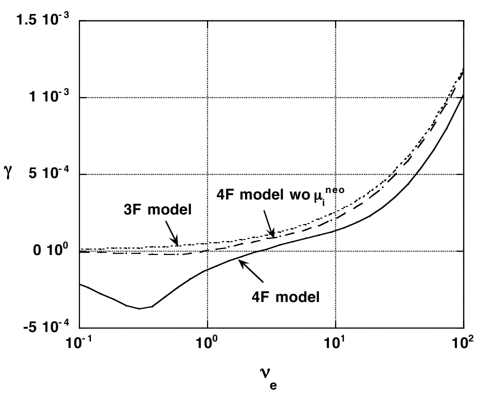

Fig.1 Dependence of growth rate on collisionality.

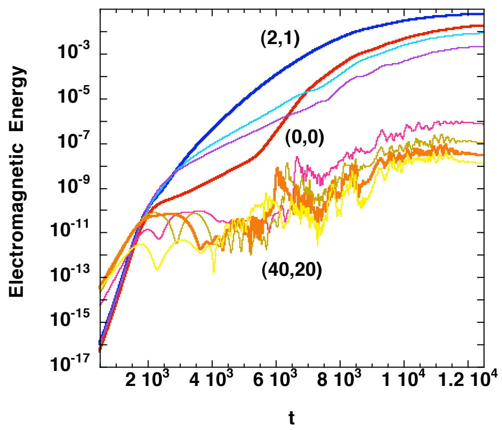

Fig.2 Time evolution of electromagnetic energy.

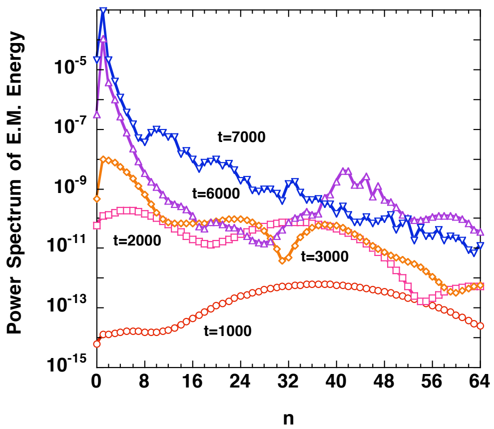

Fig.3 Power Spectrum of Electromagnetic Energy.

4. Stochastic Turbulence Trigger for NTM

A stochastic trigger by microturbulence for a NTM is studied. We obtain the stochastic equation of NTM amplitude as $\partial_t A + \eta \Lambda A = g w(t)$, where $-\Lambda$ is the nonlinear growth rate, g is the magnitude of microturbulence noise and $w(t)$ indicates white noise[3]. If there is no noise, then this equation reduces to the standard Rutherford equation. The rate of transition and statistical average of amplitude are derived and the phase boundary in plasma parameter space β_p is obtained. It is plausible that the stochastic transition without the trigger by large MHD events can be observed in high temperature plasmas if the condition $\beta_p > \beta_{p*}$ is satisfied. Formula of critical β_{p*} is derived.

5. Summary

Nonlinear simulation and statistical theory show turbulence excitation of TM is possible through several routes. Detailed comparison between theory and simulation will be performed in the aspect of incoherent noise versus coherent effect such as inverse cascade/parametric decay instability. Research on the hierarchical interaction between turbulence and MHD is important in Tokamak physics.

References

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