§3. New Saturation Mechanism of Turbulence in Finite-beta Helical Plasmas

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A saturation mechanism for microturbulence in a regime of weak zonal flow generation is investigated by means of electromagnetic gyrokinetic simulations. The study identifies a new saturation process of the kinetic ballooning mode (KBM) turbulence originating from the spatial structure of the KBM instabilities in a finite-beta Large Helical Device (LHD) plasma. Specifically, the most unstable KBM in LHD has an inclined mode structure with respect to the mid-plane of a torus, i.e. it has a finite radial wave-number in flux tube coordinates, in contrast to KBMs in tokamaks as well as ion-temperature gradient (ITG) modes in tokamaks and helical systems. The simulations reveal that the growth of KBMs in LHD is saturated by nonlinear interactions of oppositely inclined convection cells through mutual shearing as well as by the zonal flow. The saturation mechanism is quantitatively investigated by analysis of the nonlinear entropy transfer that shows not only the mutual shearing but also a self-interaction with an elongated mode structure along the magnetic field line [1].

Electromagnetic turbulence in finite-beta Large Helical Device (LHD) plasmas is studied by means of gyrokinetic simulations. The study shows common features to those found in gyrokinetic simulations of finite beta tokamaks such as the stabilization of ITG modes, the destabilization of KBMs, and weak zonal flows in KBM turbulence [2]. The turbulent transport due to the ITG in LHD plasmas with $\beta = 0.2\%$ is regulated by zonal flows, even in the presence of electromagnetic perturbations. The contribution of convective part to the energy flux is comparable with that of the turbulent diffusive heat flux part, because of the finite density gradient of the model configuration of LHD. For a small density gradient that is often observed in LHD, the contribution of the convective part can be different from the results obtained here. In addition, magnetic perturbations have small pinch effects on the energy and the particle fluxes.

A new mechanism of saturation process of KBM turbulence in LHD is presented by analysis of nonlinear entropy transfer. The analysis has revealed that the growth of KBM is saturated by nonlinear interactions of oppositely inclined convection cells with mutual shearing as well as by the zonal flow (Fig. 1). It is expected that the KBMs have inclined mode structure and are saturated through the new mechanism, when particle trapping by helical ripples is significant, because the bounce-average of magnetic drift velocity has finite radial component in the bounce-average of magnetic drift frequency to destabilize Fourier modes with finite radial wavenumber. The new mechanism may also cause saturation of turbulence in finite-beta tokamaks in the presence of three-dimensionality such as toroidal ripples and resonant magnetic perturbation (RMP). In the steady state the amplitudes of energy and particle fluxes due to KBM at $\beta = 1.7\%$ are similar to those caused by the ITG turbulence at $\beta = 0.2\%$, even though the amplitude of the KBM turbulence is larger than that of the ITG turbulence. The spectrum of electrostatic potential for the KBM turbulence is sharply peaked compared with that for the ITG turbulence (Fig. 2).

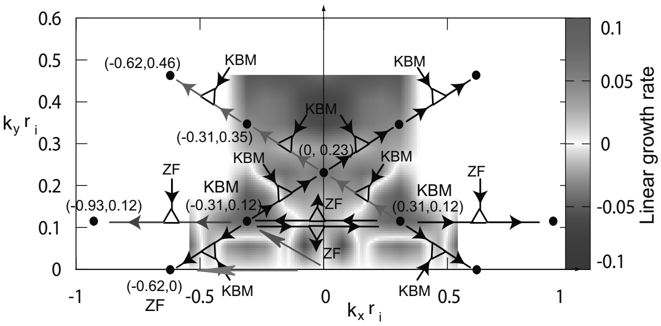

Fig. 1: Diagrams of nonlinear entropy transfer for the KBM turbulence with a color map of the linear growth rate of the KBM in the Fourier space (k_x, k_y): blue arrows show the transfer of the entropy/free-energy from KBM to linearly stable modes through zonal flow shear and red arrows show the transfer through KBM/inclined-mode shear. Black points represent the locations of Fourier modes, and ZF→ and KBM→ show the scatter by the zonal flow shear and KBM/inclined-mode shear, respectively.

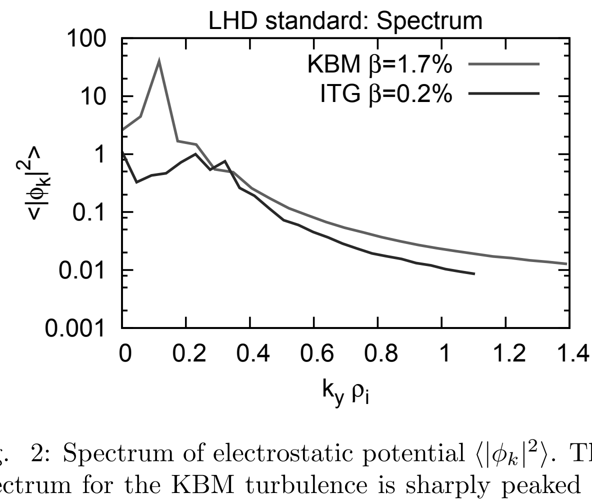

Fig. 2: Spectrum of electrostatic potential $\langle|\phi_k|^2\rangle$. The spectrum for the KBM turbulence is sharply peaked at a low wavenumber compared with that for the ITG turbulence.

1) A. Ishizawa, T.-H. Watanabe, et.al., Physics of Plasmas **21**, 055905 (2014).

2) A. Ishizawa, S. Maeyama, et.al., Nuclear Fusion **53**, 053007 (2013).