§17. Structural Formation of Drift Wave Turbulence in Cylindrical Plasmas

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Turbulent plasmas form a variety of structures such as a zonal flow and a streamer, which affect the level of anomalous transport in fusion plasmas [1]. Therefore, their self-regulated mechanism should be taken into consideration. Plasma experiments in a simple linear configuration have been carried out for quantitative understandings of the structural formation mechanism by turbulence [2]. The common process of nonlinear saturation in magnetized plasmas can be deduced, so the detailed simulation study of drift wave turbulence in a linear device has great importance to clarify the turbulent structural formation mechanism [3]. A zonal flow and streamer are formed in nonlinear states in numerical simulations, and their formation mechanisms have been studied.

We have been developing a 3-D numerical simulation code called 'Numerical Linear Device' (NLD), which describes the resistive drift wave turbulence in a linear device [3]. The three-field (density, potential and parallel velocity of electrons) reduced fluid model is adopted. This is a minimal model for analyzing the turbulent structural formation mechanism by mode coupling. The plasma has a simple cylindrical shape, and the magnetic field has only the component in the axial direction with the uniform intensity. According to experiments, high density ($n_e > 1\times10^{19}$[m^{-3}]) and low temperature ($T_e < 5$ [eV]) plasmas in an argon discharge are analyzed. The density of neutral particles is high even in the plasma core region, so the effect of neutral particles is taken into consideration.

Using the set of model equations, nonlinear simulations have been performed to examine the saturation mechanism of the resistive drift wave turbulence. A resistive drift wave can be excited with a small ion-neutral collision frequency ν_{in}, and nonlinear steady states are obtained with a fixed particle source [3]. Two kinds of turbulent structures are formed, depending on the value of ν_{in}.

If ν_{in} is small, in nonlinear steady states, nonlinear coupling of modes with weak dispersion (modulational coupling) generates the (0, 0) mode (zonal component), which affects the stability of modes. Figure 1 (i) shows a snapshot of the contour of the electrostatic potential with $\nu_{in} = 0.02$. In this case, modes with (m, n) = (0, 0), (2 – 4, 1) have the same level of amplitude, and the mode with a maximum amplitude exchanges from time to time. The mechanism of the variation is understood by observing the relationship between $E_\phi(0, 0)$ and E_ϕ of the dominant mode. Firstly, unstable modes, such as that with (m, n) = (2, 1), increase (growing phase (i)). Then, nonlinear coupling causes the growth of the (0, 0) mode (potential generation (ii)). The generated mean potential stabilizes the unstable modes, which turn to decrease (stabilizing phase (iii)). Without the nonlinear source, the (0, 0) mode can not be sustained (mean damping phase (iv)), and once the mean potential becomes small enough, the $m \neq 0$ modes begin to grow again (phase (i)). In this way, the limit cycle oscillation is generated, and the steady state is sustained.

If ν_{in} is large, the zonal flow remains stable, owing to a strong collisional damping. Three-wave coupling including modes, which has the wave number and frequency close to each other (parametric coupling), can resonantly takes place in this case. Figure 1 (ii) shows a snapshot of the contour of the electrostatic potential with $\nu_{in} = 0.1$. There formed a streamer, which is a strong vortex localized in the θ direction. The vortex structure is sustained for a much longer duration than the drift wave oscillation period, and induces localized convective transport in the radial direction. The turbulent structure has a radial scale length close to the plasma radius, not the meso scale, because of not so small typical scale length of the drift wave ρ_i compared with the plasma radius a ($\rho_i / a \sim 0.09$). However, the rotation frequency is $f_{st} = 3\times10^{-4}$, which is much smaller than that of the drift wave $f_d = 0.02$ ($f_d / f_{st} \sim 70$). The characteristics of streamers are satisfied without the typical space length, and we call the structure 'streamer'.

3-D mode coupling is essential for preservation of a streamer structure. In this case, modes with (m, n) = (4, 1) and (5, 1) are dominant, and their coupling mediated by (1, 2) mode gives matching of (4, 1) and (5, 1) to rotate with the same velocity, though the phase velocities of the linear eigenmodes are different from each other. The mode with a maximum amplitude exchanges from time to time, and evolutions of the mode amplitudes are rather periodic compared with those in the small ν_{in} case. In k_r space, when the amplitude of the (4, 1) mode increases, k_r increases, accordingly. The larger k_r tends to stabilize the mode.

In this way, turbulence with a zonal flow or streamer have been obtained by the nonlinear simulation of the resistive drift wave in cylindrical plasmas, and the formation mechanism of turbulent structures has been clarified.

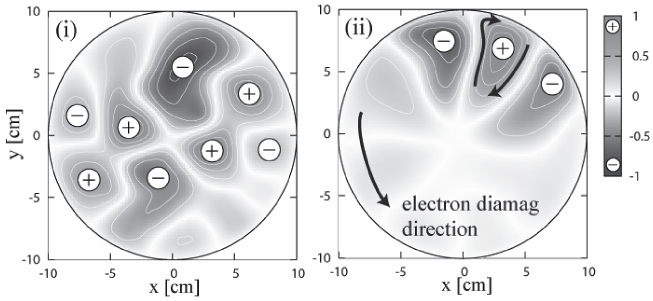

Fig.1: Snapshots of the contours of the potential, which is normalized by the maximum value at that time. The cases of (i) the zonal flow with $\nu_{in} = 0.02$ and (ii) streamer formation with $\nu_{in} = 0.1$ are shown.

1) Diamond, P. H. et al.: Plasma Phys. Control. Fusion **47** (2005) R35.

2) Terasaka K. et al.: Plasma Fusion Res.: Rapid Comm. **2** (2007) 031; Tynan, G. R. et al.: Plasma Phys. Control. Fusion **48** (2006) S51.

3) Kasuya, N. et al.: J. Phys. Soc. Jpn. **76** (2007) 044501.