§13. Turbulent Transport of Heat and Particles in a High Ion Temperature Discharge of the Large Helical Device

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Turbulent transport in a high ion temperature discharge of the Large Helical Device (LHD) is investigated by means of electromagnetic gyrokinetic simulations, which include kinetic electrons, magnetic perturbations, and full geometrical effects [1]. Including kinetic electrons enables us to firstly evaluate the particle and the electron heat fluxes caused by turbulence in LHD plasmas. It is found that the electron energy transport reproduces the experimental result (Fig. 1), and that the particle flux is negative (Fig. 2). The contribution of magnetic perturbation to the transport is small because of very low beta. The turbulence is driven by the ion temperature gradient (ITG) instability, and the effect of kinetic electrons enhances the growth rate larger than that from the adiabatic electron calculation. The ion energy flux is larger than that observed in the experiment, while the flux is close to the experimental observation when the temperature gradient is reduced 20% in the simulation. This significant sensitivity of the energy flux implies that the profile in the experiment is close to the critical temperature gradient. The critical gradient for turbulent energy flux is similar to that for the linear instability, i.e., the Dimits shift is small. This is because the zonal flow in the LHD is weaker than that in tokamaks.

Turbulent transport in a high ion temperature LHD discharge (number 88343) is studied by means of the electromagnetic gyrokinetic simulations as a validation. The plasma is unstable against the ITG mode from the core to the edge, $\rho = 0.46$, 0.65, and 0.83, and the edge region is more unstable than the core region. The kinetic electron effects enhance the growth rate two times larger than that from the adiabatic electron model. The mode structure along the magnetic field line has a ballooning structure with oscillation due to trapped particles in the helical ripples. The reduction of the growth rate by the finite beta effect is negligible because of the very small beta, $\beta = 0.3\%$.

When the beta is increased while keeping the magnetic configuration and the profiles, the kinetic ballooning mode (KBM) becomes unstable above $\beta \approx 3.5\%$. The threshold of the KBM may be influenced by the effect of the parallel component of the perturbed magnetic field $\delta B_\parallel$. The most unstable KBM has a finite ballooning angle which corresponds to a finite radial wavenumber in the flux tube coordinate [2].

In the nonlinear simulation, the turbulent ion energy flux is about three times that of the anomalous part of the experimental observation, while the flux is close to the experimental observation when the temperature gradient is reduced 20% in the simulation. Thus, the local flux tube simulation implies that the energy flux is very sensitive to the temperature gradient, and that the temperature profile realized in the experiment is close to the critical gradient of the ITG turbulence. The turbulent electron energy flux is in good agreement with the anomalous part of the experimental observation (Fig. 1). The turbulent particle flux is negative and has pinch effect (Fig. 2). The spectrum of the electrostatic potential has a peak at $k_y \rho_{Ti} \approx 0.1$ and the zonal component $k_y = 0$ has a similar level with the peak. Although the amplitude of the zonal flow is comparable with the ITG turbulence, the Dimits shift is small. This is because the zonal flow is weaker than that in the CBC tokamak which exhibits a finite Dimits shift. In helical systems, radial drift motions of particles trapped in helical ripples decrease the radial potential difference and the residual zonal flow level. This mechanism is considered to cause weaker zonal flow generation in the LHD case than in the CBC tokamak.

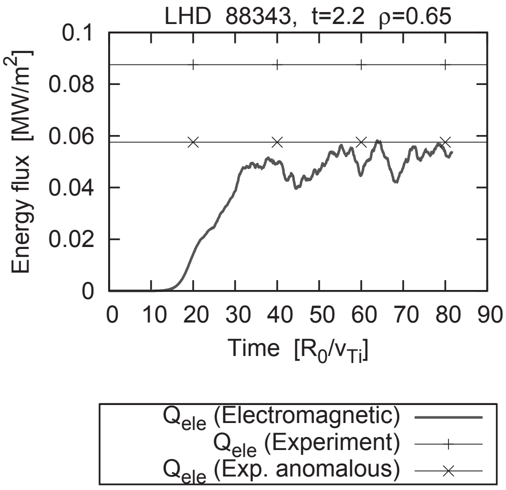

Fig. 1: Time evolution of the electron energy fluxe, Q_e.

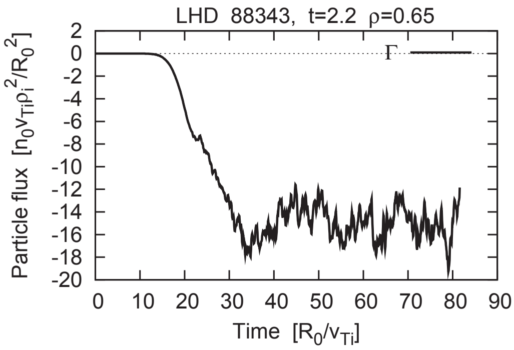

Fig. 2: Time evolution of the particle flux $\Gamma = \Gamma_i = \Gamma_e$.

1) A. Ishizawa, et.al., Nuclear Fusion **55**, 043024 (2015).

2) A. Ishizawa, et.al., Journal of Plasma Physics, **81**, 435810203 (2015).