§14. Study of the Effect of the Ripple Transport on the Confinement via Zonal Flows in Helical Plasmas

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The control of zonal flows is the key issue in fusion research. There has been much progress of the experiments on zonal flow. A number of the calculations have been done and shown the significance of the nonlinear interaction between zonal flows and the turbulence driven by the drift wave, suggesting the new framework in the simulations of plasma transport. Based on this paradigm, we have examined the reduction of the turbulent transport due to the excitation of zonal flows by the transport code analysis in the core region of helical plasmas. The electron Internal Transport Barrier (e-ITB) in helical plasmas was shown to be formed by the mechanisms of the excitation of zonal flows which causes the suppression of the turbulent transport. The transport reduction can be obtained in a wide region for E_r in conjunction with the e-ITB. In the collisionless plasmas of the Large Helical Device (LHD) in the region of the small negative electric field, if the ripple transport becomes smaller, the level of the turbulent transport gets lower. We focus on the effect of the helical ripple related with zonal flows on the confinement in the helical plasmas. The reduction of the effective helical ripple causes the smaller damping rate of zonal flows in the helical plasmas even in the branch of the small negative electric field. Not only the neoclassical but also turbulent transport is reduced by the inward shift of the magnetic axis in LHD. In the inward shifted configuration of the magnetic axis, the helical ripple transport is found to be much smaller than that in the standard configuration of magnetic axis. In the cases of the different values for the effective helical ripple, the calculation results including the effects of zonal flows is shown. The effect of the helical ripple transport on the confinement via zonal flows in helical plasmas is studied by use of the transport code analysis. We set the helical ripple coefficient as $\epsilon_{h0} = 2\sqrt{1-(2/(mq(0))-1}I_2(mr/R)$. Here, $q(0)$ is the value of the safety factor at $\rho = 0$ and I_2 is the second-order modified Bessel function. We show the calculation results for two cases of the effective helical ripple: $\epsilon_h = \epsilon_{h0}$ and $\epsilon_h = 0.1\epsilon_{h0}$. In the cases of $\epsilon_h = \epsilon_{h0}$ and $\epsilon_h = 0.1\epsilon_{h0}$, the calculations in the standard configuration and the inward-shifted configuration in LHD experiments are demonstrated.

The stationary profiles of the radial electric field, the density, the electron temperature and the ion temperature are studied as a calculation result. The effect of the helical ripple via zonal flows is examined. The radial transition from the positive radial electric field to the negative one is shown. The parameter ρ_T represents the location of this radial transition of E_r. The radial profiles of the criterion for the excitation of zonal flows, χ_{damp}, the turbulent heat diffusivity without the effect of zonal flows, χ_a and the turbulent heat diffusivity with the effect of zonal flows, χ_T, are obtained. The radial profiles of the heat diffusivity are studied in two cases: $\epsilon_h = \epsilon_{h0}$ and $\epsilon_h = 0.1\epsilon_{h0}$. In both cases, the reduction is obtained from the heat diffusivity without the effect of zonal flows χ_a to the turbulent heat diffusivity with the effect of zonal flows χ_T in the entire core region $\rho < \rho_T$. The damping rate of zonal flows is small if the value of E_r is large such as $E_r \simeq 30$kV/m in the region $\rho < \rho_T$. In the outer region $\rho > \rho_T$, the criterion for the excitation of zonal flows, χ_{damp} is larger than the turbulent heat diffusivity without the effect of zonal flows, χ_a. Therefore, the reduction from χ_a to χ_T due to zonal flows does not occur in the outer region $\rho > \rho_T$ in the case: $\epsilon_h = \epsilon_{h0}$. On the other hand, the criterion for the excitation of zonal flows, χ_{damp} gets smaller than χ_a in the region $\rho > \rho_T$, because the smaller effective helical ripple ratio lowers the criterion for the excitation of zonal flows χ_{damp}. Since the effective helical ripple gets smaller, the damping rate of zonal flows also gets smaller, even if the absolute value of E_r is less than 10kV/m in the region $\rho > \rho_T$. Therefore, the reduction from χ_a to χ_T due to zonal flows is obtained even in the outer region $\rho > \rho_T$. Finally, the analysis is performed to compare the heat turbulent diffusivities when zonal flows are excited in two cases of the effective helical ripple for the same plasma profiles (n, T_e, T_i and E_r). The radial profiles of χ_T are shown in the case: $\epsilon_h = \epsilon_{h0}$ with the solid line and in the case of the smaller helical ripple: $\epsilon_h = 0.1\epsilon_{h0}$ with the dashed line in Fig. 1. Even in the outer region $\rho > \rho_T$, the reduction of χ_T in the case of the smaller helical ripple can be obtained, comparing with the case: $\epsilon_h = \epsilon_{h0}$, because the smaller effective helical ripple lowers the criterion for the excitation of the zonal flows.

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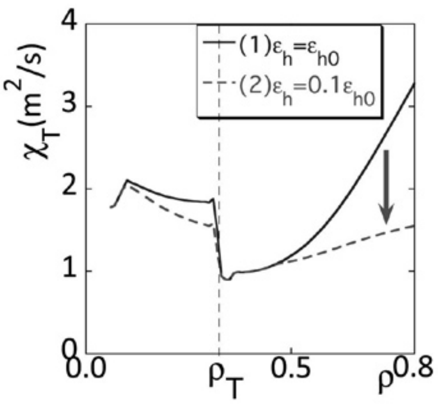

Fig. 1: Radial profile of the turbulent diffusivity in the presence of zonal flows.