Experimental study on configuration dependence of turbulent transport on LHD

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An experimental study of the magnetic configuration dependence on turbulent transport was performed in Large Helical Device[1]. To evaluate parameter dependence on ion thermal diffusivity, a transport database was developed by LHD plasma experiment with an integrated transport code (TASK3D) [2]. Two different analyses were applied to evaluate the parameter dependence on ion thermal diffusivity. One is the Akaike Information Criterion with multivariate regression, and it was found that the geodesic curvature is statistically much more important parameter than helical Fourier components of the magnetic field, in which both of them should impact on zonal flow damping. The other is the evaluation of zonal flow effect using a reduced transport model which was developed by nonlinear gyrokinetic simulations and quantitatively validated by the experimental data on LHD. The clear enhancement of zonal flow effect was observed in the low geodesic curvature configuration.

Configuration optimizations in three-dimensional magnetically confined plasma system have been intensively investigated synergistically in theory, simulation, and experiments. Significant progress was obtained in reduction of neoclassical transport and magnetohydrodynamics stability. On the other hand, optimization of turbulent transport is still an open issue in the three-dimensional systems, because large simulation costs are required for precise transport evaluation with nonlinear effects such as saturation level and zonal flow excitation etc. A nonlinear proxy model including zonal flow effects was proposed and a geodesic curvature of the magnetic field line was proposed to control the zonal flow level in ion temperature gradient (ITG) mode turbulence [1]. In this study, we experimentally investigated the geodesic curvature dependence on turbulent transport with the zonal flow effect on LHD.

A transport database based on LHD plasma experiment was developed with an integrated transport code, TASK3D. In this study, neoclassical transport was not taken into account because statistical stability became worse due to overestimate of neoclassical transport with the condition of radial electric field is small, which is discussed in detailed in the previous study [1]. To investigate the magnetic configuration dependence the radial position of magnetic axis was scanned as $R_{ax} = 3.60$ m, 3.75 m and 3.90 m with the magnetic field strength of $B_t = 2.63$ T, in which the geodesic curvature, effective ripple, helical ripple, etc, change

χ_i/χ_i^{GB}	Parameter	$\langle\kappa_g\rangle/\langle\kappa_g\rangle^{\mathrm{ref}}$	T_e/T_i	$R/L_n+R/L_{Ti}$	R/L_{Te}	ε_h	$\mathcal{T}$	ν_i^*	s
Number of parameters	Minimum AICc	exponents for each paramter selected by AIC							
		a^1	a^2	a^2	a^3	a^4	a^5	a^6	a^7
1	521.3	1.44							
2	354.4	1.25	1.39						
3	266.3	1.52	1.12	-0.422					
4	231.0	1.80	1.61	-0.460	-0.837				
5	224.1	1.97	1.65	-0.457	-0.900	0.915			
6	221.6	1.95	1.46	-0.477	-0.997	0.997	0.0920		
7	218.5	1.83	1.56	-0.377	-1.01	1.32	0.105	0.121	
8	219.9	1.85	1.54	-0.370	-0.987	2.00	0.103	0.134	-0.276

Table 1. Summary of Akaike Information Criterion and multi-regression analysis for parameters selected by AIC.

simultaneously. In this study, we focus on geodesic curvature and helical ripple because both are theoretically pointed out the significant effects on zonal flow intensity. The flux-averaged geodesic curvature weighted with a Gaussian profile with a ballooning structure, $\langle\kappa_g\rangle$, was evaluated and used in this study. We selected eight nondimensional parameters which have been known to be important for ITG mode stability and turbulent transport with zonal flow as $\langle\kappa_g\rangle/\langle\kappa_g\rangle^{\mathrm{ref}}$, T_e/T_i, $R/L_n + R/L_{T_\mathrm{i}}$, R/L_{T_e}, ε_h, T, ν_i^*, s, where T_e/T_i is temperature ratio, R/L_n is normalized density gradient, R/L_{T_i} is normalized ion temperature gradient, R/L_{T_e} is normalized electron temperature gradient, ε_h is helical Fourier component of the magnetic field, T is turbulent intensity, ν_i^* is normalized collisionality, s is magnetic shear, respectively. The summary of AIC and multivariate regression analysis is shown in Table 1. The minimum of AIC is obtained for a case with exploiting 7 parameters and the statistically most important parameter to characterize the ion thermal diffusivity is the geodesic curvature, which may affect the zonal flow intensity. The second and third parameters are strongly related to the ITG mode stability.

In order to investigate the zonal flow effects, we used a reduced transport model developed based on the nonlinear gyrokinetic simulations and quantitatively validated with experimental data on LHD [4]. In this model, $Z^{1/2}/T$ is a parameter of the zonal flow effect for reduction of turbulent transport and can be evaluated by the transport database with fixing other parameters, which is shown in Fig. 1. One can see a clear decrease of zonal flow effects with the geodesic curvature, indicating that the geodesic curvature can be used for turbulent transport optimization with zonal flow effect.

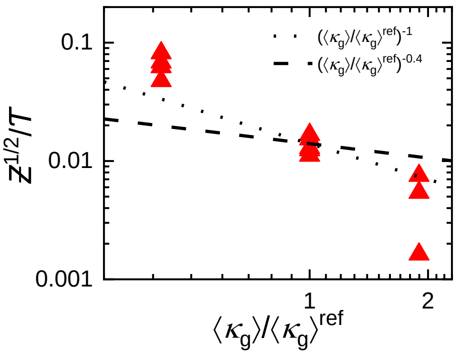

Fig. 1 Zonal flow effect as a function of normalized geodesic curvature.

In concluding, the nonlinear proxy model of turbulent transport [3] agrees with the experiment on LHD, which impacts on optimization study on three-dimensional plasmas.

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