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Geodesic Curvature Dependence of Zonal Flow in the LHD

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Control of turbulent transport is one of the most important issues in the core plasma of the magnetically confined fusion research. It is well known that zonal flow, which is driven by nonlinear coupling in turbulence, may suppress the turbulent transport. Therefore, the impact of the zonal flow on turbulent transport have been intensively studied[1].

Recently, theoretical research showed the zonal flow dependence on the geodesic curvature of the magnetic field line[2]. The geodesic curvature is proportional to the radial excursion for trapped particles, which may shield the zonal flow potential, in other words, may be a zonal flow damping effect. In this study, the geodesic curvature dependence on the ion heat transport was experimentally investigated and the zonal flow effect is discussed.

The experiment was carried out on the Large Helical Device (LHD). The geodesic curvature $\langle \kappa_g \rangle$ is controlled by the radial position of the plasma axis. We investigated parameters dependence of ion heat transport with Akaike Information Criterion (AIC). For every case of number of parameters, nonlinear multi regression analyses for the selected parameters were carried out, which is summarized in table 1. The geodesic curvature dependence is the most crucial for the heat transport and the dependence is qualitatively consistent with the theoretical study[2].

Another approach was also carried out using the reduced transport model [3]

$$\frac{\chi_{\mathrm{i}}^{\mathrm{turb}}}{\chi_{\mathrm{i}}^{\mathrm{GB}}} = \frac{C_1 \bar{\mathcal{T}}^{\alpha}}{C_2 + \bar{\mathcal{Z}}^{1/2}/\bar{\mathcal{T}}},$$

Where $\chi_{\mathrm{i}}^{\mathrm{turb}}$, $\chi_{\mathrm{i}}^{\mathrm{GB}}$, $\bar{\mathcal{T}}$, $\bar{\mathcal{Z}}$ are turbulent transport coefficient, gyro-Bohm diffusion coefficient, turbulence intensity, and zonal flow intensity, respectively. The $\chi_{\mathrm{i}}^{\mathrm{turb}}/\chi_{\mathrm{i}}^{\mathrm{GB}}$ and $\bar{\mathcal{T}}$ were evaluated by the experimental observation, then the zonal flow effect $\bar{\mathcal{Z}}^{1/2}/\bar{\mathcal{T}}$ can be obtained, which are shown in figure 1. The similar dependence on the geodesic curvature was also observed. These analyses indicate crucial importance of geodesic curvature to suppress turbulent transport and the dependence may be effective for the application to the turbulent transport optimization in three-dimensional torus plasma design.

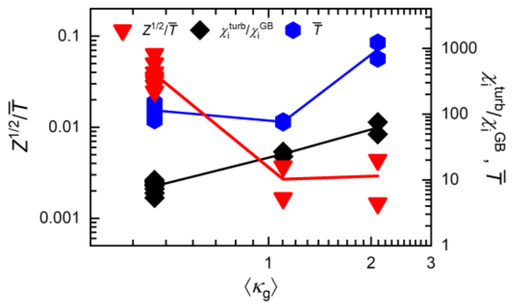

Figure 1. Geodesic curvature dependence of zonal flow effect ($\bar{\mathcal{Z}}^{1/2}/\bar{\mathcal{T}}$), turbulence ($\bar{\mathcal{T}}$), and turbulent transport coefficient normalized by gyro-Bohm diffusion coefficient ($\chi_{\mathrm{i}}^{\mathrm{turb}}/\chi_{\mathrm{i}}^{\mathrm{GB}}$).

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$\ln \chi_{\mathrm{i}}/\chi_{\mathrm{i}}^{\mathrm{GB}} = a_0 + a_1 \ln x_1 + a_2 \ln x_2 + \cdots$	AICc	Parameters and coefficients					
		$\langle \kappa_g \rangle$	$T_{\mathrm{e}}/T_{\mathrm{i}}$	$R/L_n + R/L_{T_{\mathrm{i}}}$	$R/L_{T_{\mathrm{e}}}$	ν_{ii}^*	$\tilde{n}_{\mathrm{e}}/n_{\mathrm{e}}$
	499.8	1.46					
	354.4	1.25	1.37				
	264.6	1.53	1.21	-0.428			
	218.6	1.85	1.64	-0.469	-0.960		
	219.2	1.77	1.68	-0.421	-0.948	0.0630	
	250.5	1.78	1.62	-0.427	-0.987	0.0747	0.0752

Table 1. Amount of AICc and coefficients for nonlinear multi regression analysis of ion-heat transport coefficient normalized by gyro-Bohm diffusion coefficient. The best parameter selection is yellow hatched column, where the AICc has the minimum number. The coefficients are represented as numbers in the cells.