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Study of phase dynamics in turbulent momentum and particle transport in the edge of HL-2A Tokamak

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High confinement regimes are expected to be the operation scenarios of future fusion reactors such as ITER. The transient increase in E×B sheared flows plays an important role in the L-H transition. The turbulent flux of momentum—Reynolds stress—is a mechanism thought to be responsible for the generation of sheared flow driven by turbulence [1]. Reynolds stress and fluxes are sensitive to cross phase [2]. However, usual quasilinear theory does not treat phase as dynamic. Study of cross phase influence on turbulent transport and the interaction between sheared flow and cross phase, is significant for understanding the high confinement regimes. In this report, we present the recent experimental results of cross phase influence on turbulent momentum and particle transport in the edge of HL-2A tokamak.

Ensemble-averaged Reynolds stress or particle flux is written as the product of fluctuation intensities and a cross phase factor: $\langle \tilde{v}_r \tilde{v}_\theta \rangle = \sigma_{\tilde{v}_r} \cdot \sigma_{\tilde{v}_\theta} \cdot X_{RS}$, $\langle \tilde{n} \tilde{v}_r \rangle = \sigma_{\tilde{n}} \cdot \sigma_{\tilde{v}_r} \cdot X_{PF}$ .The mathematical expressions for cross phase factors in Reynolds stress and particle flux are derived in Fourier domain, as shown by equation (1) and (2), respectively. The fluctuations and turbulent flux are measured by Langmuir probes.

$$X_{RS} = \frac{\sum_\omega P_{\tilde{v}_r\tilde{v}_r}(\omega)^{1/2} P_{\tilde{v}_\theta\tilde{v}_\theta}(\omega)^{1/2} \gamma_{\tilde{v}_r\tilde{v}_\theta}(\omega) \cos\varphi_{\tilde{v}_r\tilde{v}_\theta}(\omega)}{\left(\sum_\omega P_{\tilde{v}_r\tilde{v}_r}(\omega)\right)^{1/2} \left(\sum_\omega P_{\tilde{v}_\theta\tilde{v}_\theta}(\omega)\right)^{1/2}} \quad (1)$$

$$X_{PF} = \frac{\sum_\omega P_{\tilde{n}\tilde{n}}(\omega)^{1/2} P_{\tilde{v}_r\tilde{v}_r}(\omega)^{1/2} \gamma_{\tilde{n}\tilde{v}_r}(\omega) \cos\varphi_{\tilde{n}\tilde{v}_r}(\omega)}{\left(\sum_\omega P_{\tilde{n}\tilde{n}}(\omega)\right)^{1/2} \left(\sum_\omega P_{\tilde{v}_r\tilde{v}_r}(\omega)\right)^{1/2}} \quad (2)$$

For Reynolds stress, prominent phase scattering in the strong shear layer ($-1\ \text{cm} < r - r_{LCFS} < 0\ \text{cm}$) is found in Ohmic discharge, as shown by Figure 1(d). This indicates a phase slipping state as predicted by theory [3]. With ECRH, the product of turbulence amplitudes increases while its gradient doesn't, as shown by Figure 1(b). With ECRH, cross phase scattering decreases significantly (Figure 1 (e)) and the gradient of X_{RS} increases (Figure 1 (c)). These lead to an increasing Reynolds stress divergence, i.e. the turbulent generation of poloidal flow. This shows an agreement with the dynamics of spectral symmetry breaking in the development of poloidal torque [4].

For particle flux, phase scattering increases with RMP, as shown by Figure 2. This could be induced by field line stochastisation due to magnetic flutter. Comparative statistical study shows that, fluctuations in particle flux exhibit a big deviation from Gaussian distribution, while fluctuations in Reynolds stress don't. This suggests that edge transport models based on quasi-linear theory need to be reconsidered. This may be related to L-H transition physics.

The cross phase dynamics may be also relevant to I-mode, which shows L-mode like density profiles, but H-mode like temperature profiles, with phase slipping in heat flux but locked in particle flux. More statistical studies (skewness, kurtosis, Hurst parameter) of cross phase in Reynolds stress and particle flux are planned for future work.

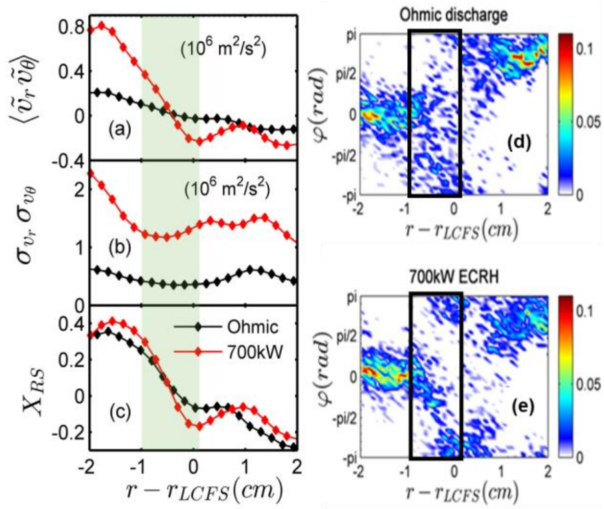

Figure 1. Cross phase in Reynolds stress.

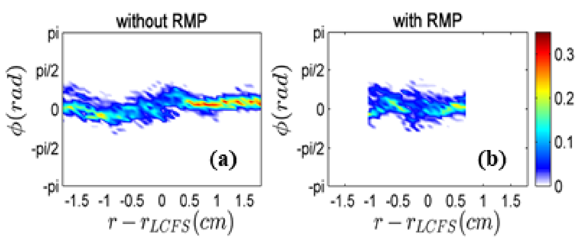

Figure 2. Cross phase in particle flux.

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