Effects of Density Gradient on Axial Flow Structures in a Helicon Linear Plasma Device

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Plasma flows along the magnetic field significantly influence impurity transport, fuel recycling, and heat deposition profile in the scrape-off layer (SOL) region. Moreover, parallel flow velocity and its radial shear are crucial to turbulence suppression and MHD stabilities, leading to enhanced confinement. Therefore, the research on mechanisms underlying the generation of parallel flows, particularly of the intrinsic flows, has drawn considerable attention.

In this study, the structures of plasma flow along the field (aka axial flow) are investigated using multi-tip Langmuir and Mach probes in a helicon linear plasma device CSDX. Experimental results show that the axial flow exists without parallel momentum input and the mean axial velocity shear $\langle v_z\rangle'$ is enhanced as the radial gradient of the plasma density increases, which recalls the observation of intrinsic flows driven by edge ∇T in C-Mod [1]. The large $\langle v_z\rangle'$ is also found to be associated with a perpendicular transport bifurcation featured as steepened density profiles, strong $E_r\times B$ flow shears and excitations of high-m modes propagating in ion diamagnetic drift direction in the core [2,3]. In lower ∇n and $\langle v_z\rangle'$ discharges, weak $E_r\times B$ flow shear and substantial total parallel Reynolds power ($-\int \langle \tilde{v}_r\tilde{v}_z\rangle'\langle v_z\rangle dA$) are observed at the plasma boundary, indicating that mean axial flow is gaining energy from the turbulence which is driven by the density gradient. In higher ∇n and $\langle v_z\rangle'$ discharges, strong $E_r\times B$ shear and suppressed total parallel Reynolds power are measured (although the local parallel Reynolds power become significant as ∇n and $\langle v_z\rangle'$ increase), but $\langle v_z\rangle'$ continues increasing until the plasma density gradient and $E_r\times B$ shear collapses. A simple model is proposed to understand the generation of the intrinsic axial flow during the transition. The increasing density gradient, together with the test axial shear flow, leads to a negative viscosity increment ($-|\chi_\phi^{res}|$), induced by the residual stress, which reduces the total turbulent viscosity ($\chi_\phi-|\chi_\phi^{res}|$). Hence the axial flow shear, driven by axial pressure drop, gets self-amplified and steepened, i.e. $\langle v_z\rangle' \sim \Delta P_i/(\chi_\phi-|\chi_\phi^{res}|)$.

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