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ExB shear flow structure and plasma self-driven current generation in magnetic island

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Plasma self-generated current plays a fundamental role in magnetic fusion. Future steady state tokamaks will rely on fully non-inductive current for generating the poloidal magnetic field needed for plasma confinement, the majority of which is from plasma self-driven current. The self-driven current also strongly affects key MHD instabilities, such as NTM and ELM. It is found that micro-turbulence can significantly affect plasma self-driven current generation. This suggests a new paradigm for turbulence to influence tokamak confinement and global stability. Computer simulations reported here employ a global gyrokinetic model coupling self-consistent neoclassical and turbulent dynamics, and simulate a consistently coupled evolution of a toroidal plasma first to a neoclassical equilibrium state for electrons, and then to a quasi-steady state with fully developed turbulence on a time scale much longer than the electron collision time. It is shown that the current amplitude, profile, and associated phase space structures can all be modified with respect to the neoclassical bootstrap current by the presence of turbulence. Turbulence can significantly reduce the current generation in collisionless regime, generate current profile corrugation near rational magnetic surfaces and nonlocally drive current in the linearly stable region [1] – all these are expected to have a broad impact on tokamak confinement and global stability. Two underlying effects, namely the electron parallel acceleration and parallel Reynolds stress drive due to turbulence, are found to play crucial roles in turbulence-induced current generation. The former drives a large scale anomalous mean current via turbulence-induced electron-ion momentum exchange, and the latter produces local current profile corrugations (at a scale of 5-10 ρ_i) around rational magnetic surfaces while keeping the total current unchanged. At a lower collisionality regime, both effects are enhanced, leading to an even greater reduction in the total electron current and more pronounced current profile corrugations. The current density profile is modified in a way that correlates with the fluctuation intensity and zonal flow gradients through their effects on $k_{//}$-symmetry breaking in the fluctuation spectrum. The magnetic island is found to strongly change ExB shear flow structure and current generation in the island region. It is shown that charge separation due to electron parallel transport induced finite electron density flattening in the O-point generate a strong radially localized ExB shear layer, which may facilitate the formation of a transport barrier near the resonant magnetic surface by decoupling plasma inside the shear layer from the outside. On the other hand, turbulence self-generated zonal flow shows a helical structure akin to the island in large island case, namely, a poloidal ExB shear flow on the perturbed magnetic surface, which may prevent the turbulence developed in the outside of the island from spreading into the O-point. The parallel mean current is also largely modified in the island region.

References

[1] W. X. Wang *et. al.*, Nucl. Fusion in press https://doi.org/10.1088/1741-4326/ab266d