Tokamak Plasma Self-driven Current Generation in the Presence of Turbulence

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Plasma self-generated current (e.g., the bootstrap current) contributes to the generation of poloidal magnetic field for plasma confinement in tokamaks, and also strongly affects key MHD instabilities. It is found that plasma turbulence may strongly influence self-driven current generation. This could have a radical impact on various aspects of tokamak physics. Our simulation study employs a global gyrokinetic model coupling self-consistent neoclassical and turbulent dynamics with focus on mean electron current. Distinct phases in electron current generation are illustrated in our initial value simulation. In the early phase before turbulence develops, the electron bootstrap current is established in a time scale of a few electron collision times, which closely agrees with the neoclassical prediction. The second phase follows when turbulence begins to saturate, during which turbulent fluctuations are found to strongly affect electron current. The profile structure, amplitude and phase space structures of electron current density are all significantly modified relative to the neoclassical bootstrap current by the presence of turbulence. Both electron parallel acceleration and parallel residual stress drive due to turbulence are shown to play important roles in turbulence-induced current generation. The former can change the total plasma self-generated current though turbulence-induced momentum exchange between electrons and ions, and the latter merely modifies the current density profile while keeping the total current unchanged. The current density profile is modified in a way that correlates with the fluctuation intensity gradient through its effect on $k_{\|}$-symmetry breaking in fluctuation spectrum. Turbulence is shown to reduce (enhance) plasma self-generated current in low (high) collisionality regime, and the reduction of total electron current relative to the neoclassical bootstrap current increases as collisionality decreases. The implication of this result to the fully non-inductive current operation in steady state burning plasma regime could be important and should be investigated. Finally, a significant non-inductive current is observed in flat pressure region, which is a nonlocal effect and results from turbulence-spreading-induced current diffusion. Work supported by U.S. DOE Contract DE-AC02-09-CH11466.