TEM Turbulence, Zonal Flows, and Tearing Fluctuations in the Reversed Field Pinch

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Standard reversed-field pinches (RFPs) are subject to large-scale tearing modes which degrade confinement quality. To combat this, RFPs can run in a special mode of operation that reduces current gradients, Pulsed Poloidal Current Drive (PPCD). Such high-performance RFP operation makes it possible for devices to enter regimes where microturbulence contributes significantly to heat and particle transport. This work focuses on the analysis of high-frequency (~50 kHz) fluctuations in recent PPCD discharges in the Madison Symmetric Torus, for which strong experimental evidence of microturbulence exists. Local gyrokinetic simulations were performed at multiple radial positions outside the reversal surface using the Gene code for both temperature gradient and density gradient dominated discharges. The dominant instability is a density-gradient-driven trapped-electron-mode (TEM), in agreement with experimental observation. Initial results on a different PPCD discharge with no experimentally observed high-frequency fluctuations indicate a different instability drive. The appearance of this density-gradient-driven TEM in the RFP creates a unique opportunity to study zonal flow physics in a magnetic-fluctuation-rich environment.

For nonlinear simulations, an accurate description of the turbulence requires the inclusion of residual tearing mode fluctuations. Though reduced in PPCD, large-scale tearing modes introduce non-negligible levels of magnetic perturbations, even at the outer radii under investigation here. In simulations, they can be seen to weaken zonal flows and degrade confinement, increasing the transport by orders of magnitude to experimentally observed levels. Importantly, these imposed fluctuations are amplified by a self-consistent plasma response, drastically increasing the fluctuation magnitude on timescales much faster than those of the characteristic turbulence. While this reinforcement is at variance with island-healing scenarios common in tokamaks, it occurs in simulations with no $E \times B$ shear flow. Selective modification of simulation parameters shows the reinforcement to be driven by parallel electron streaming and curvature. An analytic calculation is presented to describe this mechanism and verified through comparison with simulations.