Non-solenoidal Startup via Local Helicity Injection and Edge Stability Studies in the Pegasus Toroidal Experiment

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Abstract

The Pegasus Toroidal Experiment is an ultra-low aspect ratio ($A < 1.2$) spherical tokamak, enabling exploration of the unique plasma characteristics of the tokamak-spheromak overlap regime at near-unity A. Major research thrusts include: development of non-solenoidal plasma initiation and current growth via local helicity injection (LHI); attainment and study of high β_T plasmas in the regime of high normalized current ($I_N > 10$) or high toroidal field utilization factor ($I_p/I_{TF} > 1$); and tokamak edge stability, via unique experimental tests of the peeling-ballooning stability theory that underlies deleterious Edge Localized Mode (ELM) activity of concern to ITER. LHI has produced non-solenoidal tokamak plasmas with $I_p > 0.15$ MA in Pegasus by injecting helicity with DC edge current drive in the plasma periphery. The technique is constrained by helicity injection rates, resistive dissipation, and an I_p limit arising from Taylor relaxation. Following initiation via active arc plasma sources, additional helicity injection may be provided by shaped electrodes. Such structures may be simultaneously optimized with respect to the helicity and Taylor relaxation limits. Bursts of MHD activity during the growth phase are correlated with rapid equilibrium changes, redistribution of the toroidal current density, and observations of strong ion heating ($T_i \sim 1$ keV). The impedance of active injectors and thereby their helicity input rate appears constrained by a double-layer space charge limit at low currents and the Alfvén-Lawson current limit for intense electron beams at high currents. The understanding developed in these studies support scalability of the helicity injection technique to large devices. Operation at near-unity A and high I_p/I_{TF} provides J_{edge}/B instability drive for peeling modes in Pegasus. The modest temperatures and pulse length of Pegasus permit detailed study of their properties, including unique time-resolved local measurements of the edge current density critical to stability predictions. Peeling modes generate edge-localized, low-n (≤ 3) electromagnetic activity with amplitudes that scale strongly with measured J_{edge}/B instability drive, consistent with theory. Nonlinearly, peeling modes produce ELM-like, field-aligned, current-carrying filaments from an initial current-hole J_{edge} perturbation that detach from the edge and propagate outward. Their constant-velocity radial motions are in qualitative agreement with rates given by electromagnetic blob transport theory. Ohmic H-mode has recently been achieved following installation of a new central column fueling system. Initial H-mode plasmas in Pegasus exhibit reduced D_α emission, improved energy confinement, a reversal in toroidal rotation at the L-H transition, and access to Type I and III ELMs. Local J_{edge} measurements indicate formation of an edge current pedestal in H-mode, as well as evidence of current-hole perturbations during Type III ELM crash events.

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