Plasma Startup via Local Helicity Injection and Advanced Tokamak Physics at Near-Unity Aspect Ratio in the PEGASUS Experiment

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Experiments on PEGASUS have furthered the understanding of high-current, non-solenoidal spherical tokamak startup via local helicity injection (LHI). A current-source development campaign showed that an array of active plasma arc sources is preferred for extrapolating to MA-class I_p startup. Arc current injector designs were improved by incorporating local scraper limiters, piezoelectric fueling capability, and a PMI-mitigating convex bias cathode structure. The maximum I_p achievable via LHI startup is constrained by limits from either helicity conservation or Taylor relaxation, but these limits do not predict the I_p actually achieved in a given plasma scenario. Comparison of a predictive 0-D power balance model for $I_p(t)$ to data from PEGASUS indicates that outboard-injection PEGASUS discharges are dominated by inductive voltages rather than the LHI effective voltage. In contrast, the regime where helicity drive dominates is relevant to MA-class startup on fusion facilities, and will be tested on PEGASUS with a new integrated 8-injector array. Resistive MHD simulations using the NIMROD code indicate that the injector-driven current streams are persistent during LHI, with the tokamak-like plasma being built up from axisymmetric rings of plasma that are formed by reconnection between adjacent turns of the driven current streams. These features are in qualitative agreement with I_p jumps accompanying n = 1 MHD bursts in PEGASUS. The n = 1 MHD magnitude is also correlated with very high ion temperature ($T_i \sim 1$ kV) and indicative of strong reconnection activity.

Operation at near-unity A provides ready access to advanced tokamak phenomena in a relatively low-temperature device that can offer unique diagnostic access. These include: H-mode operation via Ohmic heating with or without a separatrix; low collisionality with $T_e < 0.5$ keV; strong particle trapping and associated neoclassical effects; and access to peeling and eventually peeling-ballooning modes for ELM studies. Operation with high-field-side fueling produces H-mode plasmas and an associated pedestal in the plasma current density at the edge. This $J_{edge}(R,t)$ pedestal relaxes to levels typical of L-mode plasmas at the occurrence of an ELM, then quickly recovers. The filaments of plasma density and current ejected at the occurrence of a peeling instability evolve in time consistent with electromagnetic blob theory. Tests of neoclassical theory at $A \sim 1$ initially include measurements of the strong resistivity enhancement and large edge bootstrap current expected in these discharges.