A Predictive Model for Non-solenoidal Startup using Local Helicity Injection

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Local helicity injection (LHI) aided by outboard poloidal-field (PF) induction is a routine tool for non-solenoidal startup on PEGASUS. To date, plasma currents $I_p \leq 0.18$ MA have been achieved using up to 6 kA of externally injected current. LHI discharges on PEGASUS are created near the outboard injectors with aspect ratio (A) ≈ 5 and grow inward to fill the confinement region at A ≈ 1.3. This extreme change in geometry results in large inductive voltages on the plasma. A predictive, lumped-parameter circuit model for LHI plasma current evolution is in development to guide injector requirements for systems on PEGASUS and potentially NSTX-U. The model employs power and helicity balance, using low-A formulations for both the plasma external inductance and equilibrium-field to estimate inductive loop-voltages in the moving plasma frame. Initial results match experimental $I_p(t)$ trajectories within 20 kA using a prescribed plasma geometry evolution. Validation of the model with equilibrium reconstructions of PEGASUS discharges is in progress. The ultimately achieved I_p is strongly dependent on the initial I_p attained when the injected current relaxes to a tokamak-like state. This early I_p is consistent with both a Taylor relaxation current limit and a kink instability limit. Helicity injection is the largest driving term in the initial phase of the plasma evolution, but in the later phase is reduced to 20-30% of the total drive as PF induction and decreasing plasma inductance become dominant. In contrast, MA-class startup on NSTX-U and beyond will require operation in the regime where helicity injection drive exceeds inductive and geometric changes when the plasma is at full size. Experiments using upgraded injector systems with high-voltage capability ($V_{bias} \leq 1.5$ kV) are underway to explore plasma behavior and test the model in this helicity-dominated regime on PEGASUS.

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