ABSTRACT

Initiatives in Non-Solenoidal Startup and Edge Stability Dynamics at Near-Unity Aspect Ratio in the PEGASUS Experiment

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The PEGASUS research program exploits unique aspects of tokamak properties at near-unity aspect ratio to pursue fusion science studies in three areas: 1) nonsolenoidal startup of tokamak plasmas; 2) detailed studies of plasma edge stability in the H-mode regime; and 3) MHD stability boundaries at high beta and toroidicity. An initiative to upgrade the PEGASUS facility–longer pulse, increased B_{TF}, separatrix operation–will extend these studies to test predictive models of these phenomena.

Startup of a spherical tokamak (ST) without an Ohmic solenoid benefits designs for a FNSF based on the ST, and may be valuable to tokamak reactors in general. Local Helicity Injection (LHI) uses high intensity electron current sources in the plasma edge region to inject DC helicity into the bulk plasma and thereby drive toroidal current. The resulting I_p is limited by helicity conservation and Taylor relaxation constraints. A 0-D power balance model describes the measured $I_p(t)$ evolution, but requires characterization of the confinement properties. Nonlinear MHD simulations using the NIMROD code suggest repetitive reconnection interactions inject axisymmetric current-carrying rings from the edge into the plasma core region. A longer pulse length and increased B_{TF} will support tests of these models and allow measurements where helicity input dominates current drive compared to inductive effects arising from changing plasma geometry. This regime is dominated by transport during LHI and is most relevant to NSTX-U and FNSF applications. Longer pulse and high BTF also enable development of injector technology appropriate for use in LHI startup systems for NSTX-U and FNSF.

Tokamak operation at very low aspect ratio allows stable high I_p at low B_{TF}. This provides a very low threshold power for transition to the H-mode confinement regime, which is readily achieved using Ohmic heating only. Measurements of a peeling mode clearly show the evolution of a hole in $J_{edge}(R,t)$ and ejection of a current-carrying filament consistent with electromagnetic blob theory. These edge current measurements are being extended to the peeling-ballooning regime encountered with H-mode excitation of ELMs, where the nonlinear multimodal collapse of $J_{edge}(R,t)$ is readily observed. Such measurements directly support the development of ELM understanding for projection to ITER. Longer pulse and separatrix operation will facilitate detailed nonlinear ELM studies in H-mode plasmas that reach transport equilibrium. Measurements with high time and space resolution during repetitive ELM cycles will allow comparisons to model calculations from relevant codes such as NIMROD, BOUT++, and EPED.

New nonsolenoidal startup techniques and tests of ELM mitigation are under consideration for the latter part of the next decade. Access to high I_p will test the limits of the tokamak configuration at high toroidicity and high field utilization, where $I_p >> I_{TF}$.

These experiments are amenable to strong graduate student participation and leadership, and provide critical research and development activities in support of the larger fusion program goals. These activities directly support ReNew Theme 5, Thrust 16 (Developing the ST to advance FNS), and indirectly Theme 3 (Taming the Plasma-Material Interface) through pedestal stability studies and development of high-power current injector technology compatible with the edge of a high-performance plasma.