Topic: OV

# Recent Physics Results from the National Spherical Torus Experiment

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The National Spherical Torus Experiment (NSTX) has made considerable progress in advancing the scientific understanding of high performance long-pulse plasmas needed for low-aspect-ratio spherical torus (ST) concepts and for ITER. Plasma durations up to 1.5s (approximately 5 current redistribution times) have been achieved at plasma currents of 0.7 MA with non-inductive current fractions approaching 70% while achieving $\beta_T$ and $\beta_N$ values of 16% and 5.7 (%mT/MA), respectively. This performance has been achieved by operating with increased boundary triangularity at high elongation, utilizing advanced shape control, and from a reduction in the severity of Edge-Localized Modes (ELMs) at high elongation. NSTX now routinely operates with sustained boundary elongation up to 2.5, and as evident in Figure 1, this has translated into an increase in the product of bootstrap fraction (proportional to $\varepsilon^{1/2}\beta_P$) and $\beta_T$. Successful implementation of a novel Motional Stark Effect (MSE) diagnostic capable of measuring magnetic field-line pitch at the low toroidal fields of NSTX has produced new physics understanding. For instance, the longest duration discharges of NSTX tend to maintain a central q near unity for several current redistribution times. Thus, NSTX may offer additional insight into mechanisms for sustaining the "hybrid-scenario" being proposed as a possible improved high-Q scenario for ITER.

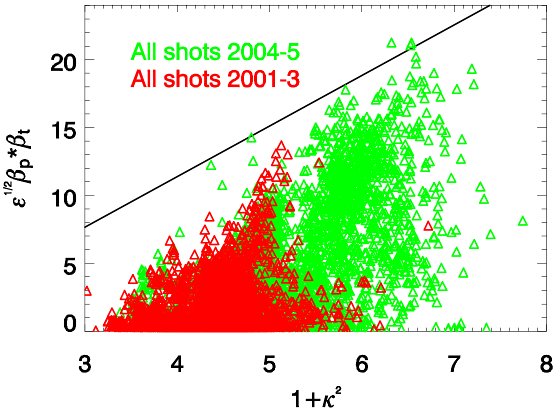


*Fig. 1 – Scaling of product of bootstrap current fraction (proportional to $\varepsilon^{1/2}\beta_P$) and $\beta_T$(%) versus elongation in NSTX.*

In transport and turbulence research on NSTX, the role of magnetic shear is being elucidated in discharges in which electron energy transport barriers are observed. In these L-mode discharges, electron energy confinement improvement correlates with the degree of measured magnetic shear reversal. In contrast, in positive shear H-mode discharges, pellet-induced edge temperature perturbations allow the core electron transport response to be probed and indicate stiff core electron transport. These transport experiments coupled with a newly commissioned high-k scattering diagnostic capable of measuring electron gyro-radius-scale turbulence will provide strong tests of anomalous electron energy transport theories - of particular importance to the predominantly electron-heated plasmas of ITER. The low aspect ratio and wide range of $\beta$ values accessible in NSTX ($\beta_T$ up to 40%) provide unique data for understanding the dependence of confinement on these parameters for the ST and for ITER. Thus far, these scaling studies indicate a weaker dependence on plasma current than at conventional aspect ratio and a significant dependence on $B_T$. In terms of physics variables, larger $\varepsilon$ and lower normalized gyro-radius $\rho_*$ and collisionality $\nu_*$ are favorable, whereas the $\beta$ scaling varies from unfavorable ($B\tau\sim\beta^{-0.65}$) to null ($\sim\beta^0$), depending on the statistical analysis method used.

In the area of MHD research, six mid-plane ex-vessel coils which produce controllable radial magnetic field perturbations have been utilized to infer and correct intrinsic error fields, investigate locked tearing mode thresholds to contribute to ITER threshold scaling studies, provide robust rotation control with non-resonant n=3 field ripple, and measure the resonant field amplification spectrum of rotationally-stabilized resistive wall modes (RWMs). Significant progress has also been made in comparing measured flow damping induced by non-axisymmetric fields to Neoclassical Toroidal Viscosity theory. In addition, similarity experiments with DIII-D and JET investigating the RWM critical rotation frequency scaling with aspect ratio are providing insight into the dissipation mechanism responsible for RWM stabilization from plasma rotation. Active feedback capabilities available this year on NSTX are expected to provide dynamic error field correction and the first tests of n=1 RWM control in ITER-relevant low-rotation plasmas utilizing n=3 magnetic braking.

Edge stability, transport, and control studies have also benefited from several new capabilities. For instance, the Lithium Pellet Injection (LPI) system has also been utilized for Lithium surface conditioning and has demonstrated the significant particle pumping capabilities of Lithium. This has motivated the installation of a Lithium evaporator as a density control tool to be tested this year. Plasma shape control has also been enhanced by successfully implementing rtEFIT from General Atomics. This capability has been exploited in similarity experiments with MAST and confirm a minimum in power threshold for H-mode access with a balanced double-null (DN) shape. ELM severity is also observed to be very sensitive to magnetic balance, with the optimal ELM characteristics typically obtained in a shape with negative bias, i.e. toward lower single null. High elongation balanced-DN shapes maintained during the current ramp have also resulted in H-mode regimes with pedestal temperatures nearly twice those of typical H-modes and the first evidence of current-hole formation in the plasma core.

NSTX is particularly well suited to investigate fast-ion driven instabilities and their influence on fast particle confinement, since Neutral Beam Injection heated NSTX plasmas can match and exceed the fast-ion $\beta$ and velocity ratio $v_{fast} / v_{Alfven}$ of ITER (albeit at much higher fast-ion $\rho^*$) with complete diagnostic coverage. Cyclic neutron rate drops have been associated with the destabilization of multiple large Toroidal Alfven Eigenmodes (TAEs) similar to the “sea-of-TAEs” predicted for ITER, albeit at lower TAE toroidal mode number $n$=1-6. Neutral Particle Analyzer data shows the strongest particle density modulation occurs below the injection half-energy and that the density of the highest energy ions is modulated by roughly 10%. The amplitude, structure, and three-wave coupling of these modes has been measured with reflectometry, soft X-ray, and Mirnov diagnostics, and this data is being compared to theoretical predictions of the mode characteristics incorporating the measured safety factor profiles.

Finally, non-inductive plasma start-up research is particularly important for the ST concept, and Coaxial Helicity Injection (CHI) has now produced 60kA of persistent current on closed flux surfaces in NSTX. High-Harmonic Fast Wave (HHFW) electron heating to $T_e$ = 1.5keV at low $I_P$ = 300kA has been demonstrated in heating conditions which minimize parametric decay instabilities. These results suggest HHFW heating and bootstrap-overdrive ramp-up of CHI plasmas may ultimately be possible.

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