NSTX
National Spherical Torus Experiment • PROGRAM HIGHLIGHTS
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Dramatic Progress Toward Solenoid-Free Operation in NSTX

A distinguishing feature of the tokamak and spherical torus magnetic confinement configurations is the large toroidal plasma current required to confine the hot plasma particles. This current is commonly initiated and sustained inductively for a limited duration by swinging the current in a solenoid passing through the center of the device (see Figure 1). This technique is intrinsically limited by the achievable solenoid current, so to sustain the plasma for long durations, alternative current sources are required. In the experiments reported here, energetic neutral particle beam injection (NBI), and the internal plasma pressure driven "bootstrap" current were used to help sustain the plasma current.

During the last experimental campaign (February – June 2002), NSTX made dramatic progress toward achieving such self-sustained plasmas. The development of several new operational techniques and physics insights by the NSTX Team has been crucial to the progress so far. Energetic neutral beams up to 7 MW in power were injected to heat "tear-drop" shaped plasmas (see Figure 1) to access the "high-confinement" mode (H-mode) with relatively stable and quiescent plasma edge. This in turn reduced the plasma resistance and the required induction from the solenoid. The plasma current was held at 0.8 million amperes while the magnetic field applied around the torus axis was 0.5 Tesla. These values of current and field improved stability of the plasma core and raised the bootstrap current. The broad H-mode plasma profiles further enhanced the achievable plasma pressure.

The energy, power, and hence the momentum of the injected energetic particles were adjusted to optimize the resulting plasma conditions. A plasma spin around the torus axis as high as 300 km/s was measured in these plasmas, which is calculated to contribute to the stability and energy containment efficiencies of the plasma. The plasma pressure was consistently higher than limits calculated according to conventional stability theories.

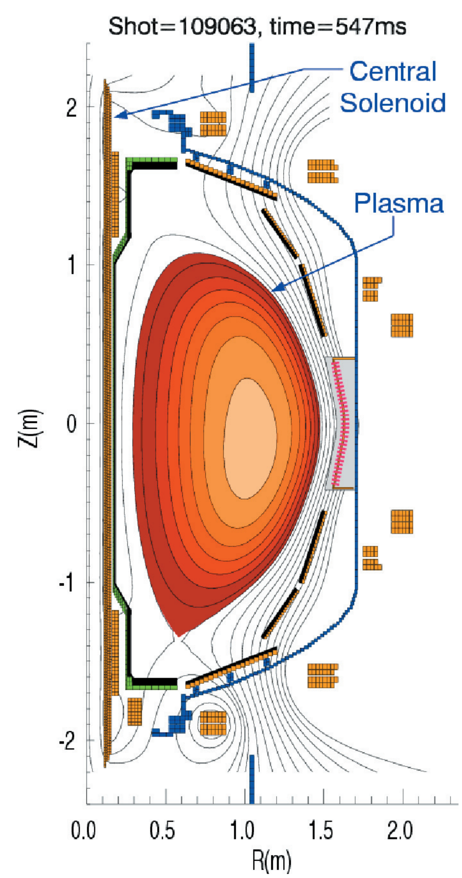


Figure 1: "Tear-drop" shaped plasma cross section used in NSTX to test the physics for approaching solenoid-free operation.

Figure 2 shows some details of a beam-driven discharge obtained with the above techniques. This discharge reached just over 1 second, which doubled the total duration obtained from the previous campaign. The plasma pressure normalized to the magnetic field produced by the plasma current (β_P) also doubled in FY 2002 to the range of 1.2 – 1.4, approaching the aspect ratio of the plasma (the ratio of the torus radius to the radius of the plasma cross section). This led to large increases in the bootstrap current, which when combined with the current driven directly by the energetic particle beam, led to drastic reductions of the inductive voltage from the solenoid.

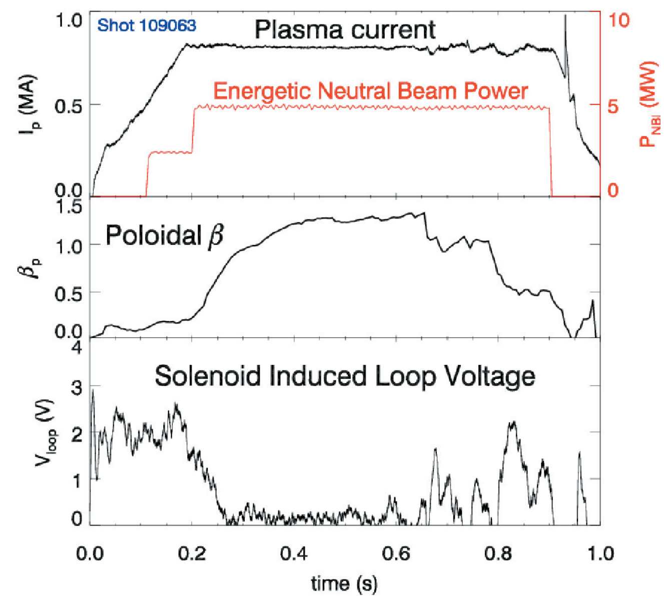
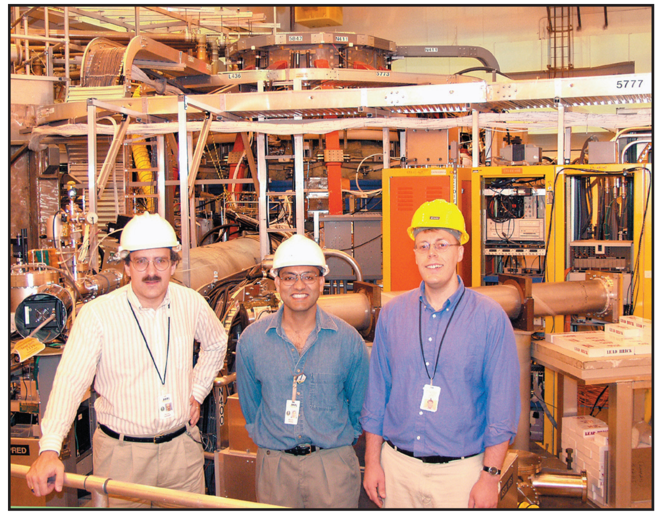


Figure 2: Plasma durations were increased substantially in NSTX when the required solenoid induced loop voltage was much reduced via improved plasma conditions that increased the pressure-driven bootstrap current. bootstrap current.



From left to right, NSTX Team members Steve Sabbagh of Columbia University, Rajesh Maingi of Oak Ridge National Laboratory, and Jon Menard of PPPL are testing the ST plasma conditions used to achieve sustained high performance toroidal plasmas.

Using models developed successfully for conventional tokamaks, the solenoid-free fraction of the plasma current is presently estimated to be over half in this and similar plasma discharges. The duration of the stationary phase of the discharge is longer than the time scale in which the plasma current is redistributed, which is estimated to be one-quarter of a second. The study of plasmas with relaxed current profiles is an important goal of these experiments. These results of simultaneous high β_P and long pulse relative to the current redistribution time compare well with recent progress made in tokamaks and represent a significant step toward steady-state sustainment of fusion plasmas.

About NSTX

NSTX is a national magnetic fusion experimental facility, located at the U.S. Department of Energy's Princeton Plasma Physics Laboratory, to test the physics principles of the innovative Spherical Torus (ST) confinement concept. The ST concept promises new opportunities for exciting scientific discoveries toward an optimized confinement system and an affordable energy development path. The NSTX National Research and Facility Operations Teams have produced exceptional results since the start of experimentation in September 1999.

NSTX Program participants include scientists from: Princeton Plasma Physics Laboratory; Oak Ridge National Laboratory; University of Washington; Columbia University; General Atomics; Johns Hopkins University; Los Alamos National Laboratory; Nova Photonics; Lawrence Livermore National Laboratory; University of California - San Diego; University of California - Davis; University of California - Los Angeles; Massachusetts Institute of Technology; University of California - Irvine; Sandia National Laboratory; Princeton Scientific Instruments; CompX; Lodestar; New York University; University of Maryland; and Dartmouth University.

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