

Coaxial Helicity Injection produces a self-contained plasma ring in the National Spherical Torus Experiment

Until now, almost all tokamaks and spherical torus plasma confinement devices have relied on a solenoid, through the center of the device, to produce the plasma current needed to confine the plasma. Recently, a process called Coaxial Helicity Injection has been applied in the National Spherical Torus Experiment to generate a self-contained ring of plasma carrying a current, without using a solenoid. Such an alternate method for plasma startup is essential for developing a fusion reactor based on the spherical torus concept and could reduce the cost of a future tokamak reactor as well.

The “spherical torus” or “ST” plasma confinement configuration is a special form of the tokamak that has been at the forefront of fusion research for over thirty years. Previously, almost all tokamaks and STs have relied on a long magnetic field coil, known as a solenoid, through the center of the device to produce the plasma current needed to confine the plasma. Since in the ST, the central column is extremely narrow, providing space for this solenoid is a major issue in their design. An alternate method for plasma startup is essential for developing fusion reactors based on the ST concept and could reduce the cost of tokamak reactors as well.

A talk to be presented at the 47th Annual Meeting of the APS Division of Plasma Physics in Denver Colorado [paper G03.11 by R. Raman *et al.*] will describe how a process called Coaxial Helicity Injection (CHI) has recently been applied in the National Spherical Torus Experiment (NSTX) at the U.S. Department of Energy’s Princeton Plasma Physics Laboratory to generate, without using a solenoid, a self-contained ring of plasma, shaped like a doughnut and carrying a current that produces closed surfaces of magnetic flux. The CHI technique has previously been studied in smaller experiments, such as the Helicity Injected Tokamak (HIT) and its successor HIT-II at the University of Washington.¹ However, these CHI experiments on NSTX represent a proof of principle for this innovative technique applied to a much larger device.

In this method, the plasma current is produced by discharging an electrical capacitor bank between coaxial annular electrodes inside the NSTX vacuum chamber. The plasma is created by electrical breakdown from a small amount of deuterium gas introduced into the chamber. When this plasma forms in the presence of a specially shaped magnetic field generated by coils surrounding the chamber, it rapidly expands and develops a toroidal electric current encircling the axis of the electrodes. This toroidal current can be much larger than the injected current. If the injected current is then rapidly decreased, a process called magnetic reconnection occurs near the injection electrodes, so that the toroidal plasma current forms and flows on closed surfaces of magnetic flux. The magnetic reconnection occurring in these experiments is similar to processes in the corona of the sun that lead to solar flares.

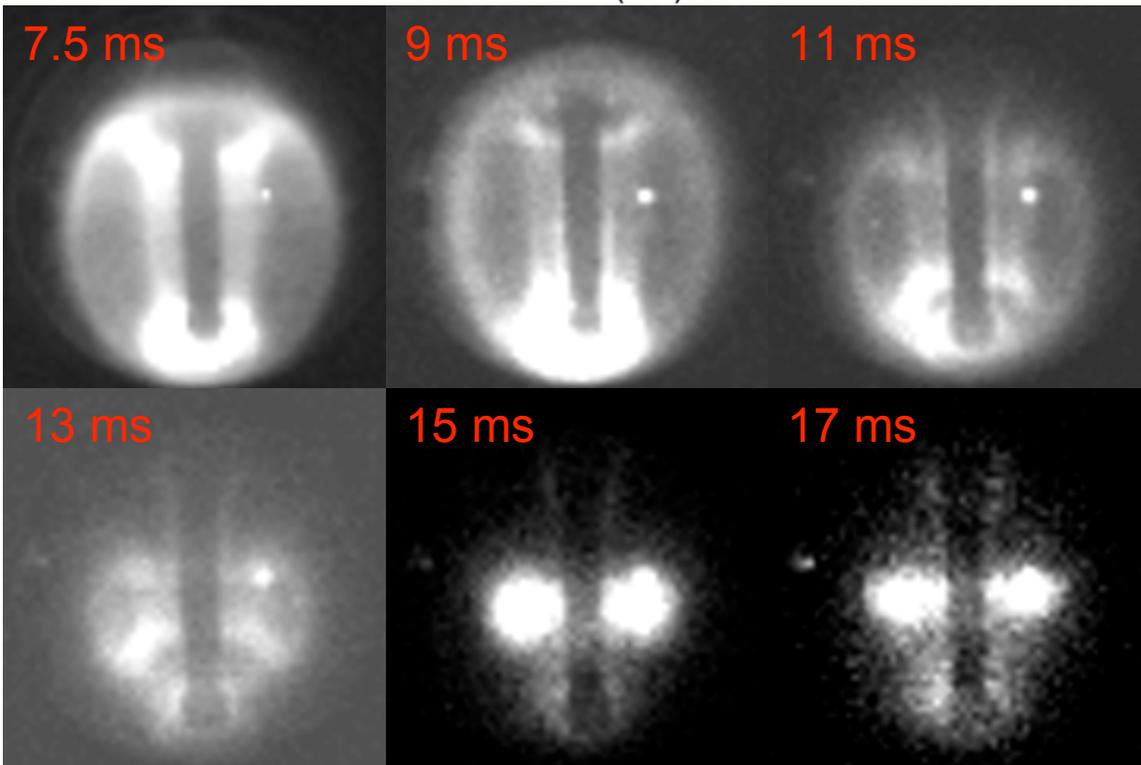
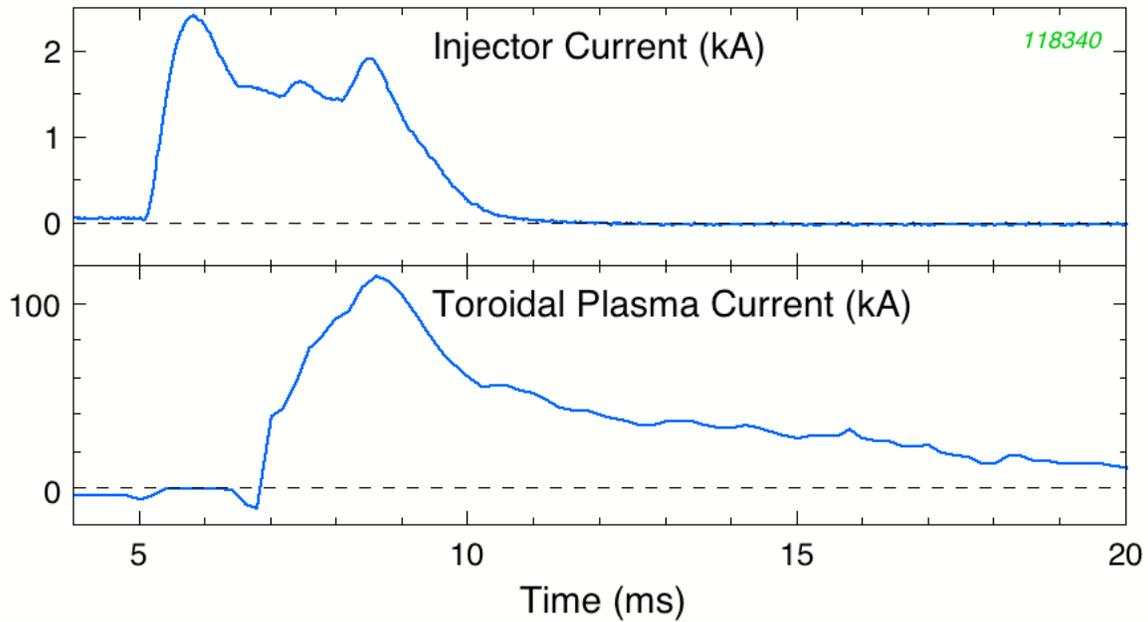
In the NSTX experiments, up to 60,000 Amperes of current was produced using only about 7,000 Joules of energy from the capacitor bank. Shown in the Figure below are waveforms recorded for the current injected from the capacitor bank and the resulting toroidal plasma current which is magnified many times over the injected current. Even after the injected current returns to zero around 11 milliseconds (ms) in this example, the toroidal current continues to flow in the plasma for about another 10 milliseconds. Also shown are images of the glowing plasma during the formation of the plasma ring. These were recorded by a high-speed camera observing the interior of the vacuum chamber through a window. The discharge grows upwards from the injector electrodes, then detaches from them to form the doughnut-shaped ring, or torus, surrounding the dark central column. This ring persists after the injector region has again gone dark, indicating the absence of a discharge there.

CHI research on NSTX is a collaboration between researchers from the University of Washington and Princeton Plasma Physics Laboratory. The high-speed camera was provided to NSTX by a collaborator from Nova Photonics, Inc.

¹ [R. Raman, T.R. Jarboe, B.A. Nelson *et al.*, “Experimental demonstration of plasma startup by coaxial helicity injection,” *Physics of Plasmas* **11**, 2565 (2004)].

Contact:

Michael Bell, 609-243-3282, mbell@pppl.gov



The time-traces above show the injector current provided by the capacitor bank (upper panel), and the resulting toroidal plasma current (lower panel) which persists after the injector current has returned to zero. The sequence of camera images below shows fish-eye views of the interior of the NSTX vacuum vessel. The dark vertical band is the center column containing some of the magnetic field coils. The lower bright region seen in the earlier images is the injector which becomes dark when the injector current ceases. The diffuse glow after 11 ms is the doughnut of plasma carrying the toroidal current encircling the center column. The fixed bright spot to the right of the center column is light from a hot filament which is used to assist in forming the initial discharge.