Topic: EX-W

Solenoid-free Plasma Start-up in NSTX using Transient CHI*

R. Raman[1], T.R. Jarboe[1], M.G. Bell[2], B.A. Nelson[1], D. Mueller[2], R. Maqueda[3], B. LeBlanc[2], J. Menard[2], and The NSTX Research Team

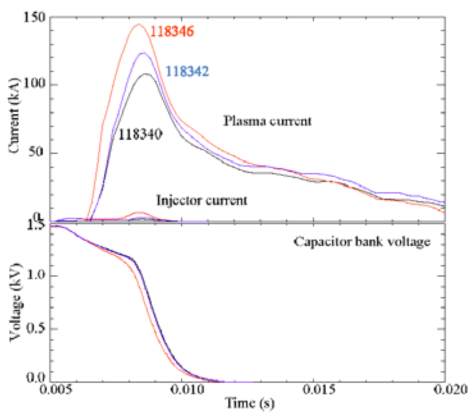
[1]University of Washington, Seattle, WA, USA
[2]Princeton Plasma Physics Laboratory, Princeton, NJ, USA
[3]Nova Photonics, Princeton, NJ, USA
e-mail: raman@aa.washington.edu

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 (CHI) has been applied in the National Spherical Torus Experiment to generate a self-contained ring of plasma carrying 60 kA of closed flux 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 also reduce the cost of a future tokamak reactor as well.

In the CHI method, a plasma current is rapidly produced by forming a discharge between coaxial electrodes connected to an external power supply in the presence of toroidal and poloidal magnetic fields. The initial poloidal field configuration is chosen such that the plasma rapidly expands into the chamber. When the injected current is rapidly decreased, magnetic reconnection occurs near the injection electrodes, with the toroidal plasma current forming closed flux surfaces. The CHI technique has previously been studied in smaller experiments, such as the HIT-II device at the University of Washington [1].

The method has now been successfully used on NSTX for an unambiguous proof-of-principle demonstration of closed-flux current generation without the use of the central solenoid. CHI is implemented in NSTX by driving current along field lines that connect the inner and outer lower divertor plates (the injector region). For experiments reported here, a 15 or 20 mF capacitor bank was used at up to 1.5 kV to provide the injector current. The standard operating condition for CHI in NSTX uses the inner vessel and inner divertor plates as the cathode while the outer divertor plates and vessel are the anode. The operational sequence for CHI involves first energizing the toroidal field coils and the poloidal field coils to produce the desired flux conditions in the injector region. The CHI voltage is then applied to the inner and outer divertor plates and a pre-programmed amount of gas is injected in a cavity below the lower divertor plates. These conditions cause the gas in the lower divertor region to ionize and result in current flowing along helical magnetic field lines connecting the lower divertor plates. The applied toroidal field causes the current in the plasma to develop a strong toroidal component, the beginning of the desired toroidal plasma current. If the injector current exceeds a threshold value, the resulting ΔB_{tor}^2 $(J_{pol} \times B_{tor})$ stress across the current layer exceeds the field-line tension of the injector flux causing the helicity and plasma in the lower divertor region to move into the main torus chamber.

In Figure 1, we show traces for the plasma current, the injector current and fast camera images at two different times during the discharge. Note that the plasma current is amplified many times over the injector current. The discharge is initiated at 5 ms after which it rapidly grows to fill the vessel within about 2 ms. Starting at about 9 ms the discharge begins to disconnect from the injector electrodes after which the injector current is essentially zero and about 60 kA of plasma current is present. Note that at 13 ms, the ring shaped plasma is clearly disconnected from both the injector and the upper divertor plate regions. As time progresses, the large bore plasma that fills the vessel shrinks in size ending as a small diameter ring, as seen in the 17 ms time frame image. The formation of closed flux regions is clearly seen in the camera frames corresponding to 13 ms and beyond. Since there is no injector current present during this period, the only plausible explanation for the left over plasma current is that it must result from a decaying closed magnetic flux configuration. For these discharges, circuit calculations show that only about 7 kJ of capacitor bank energy is expended to generate 60 kA of closed flux current. In general, the Thomson scattering electron density and temperature profiles become less hollow as time progresses (see figure). This is expected since initially CHI drives current at the edge. After reconnection in the injector region, one expects the current profile to flatten, which should result in the profiles becoming less hollow. The measured electron temperatures of about 15 - 20 eV, combined with a plasma inductance of about 0.5 - 1 μH, should result in an e-folding current-decay time on the order of about 5 ms, which is consistent with the observation that the current persists for about 10 ms after the injector current has been reduced to zero. In some discharges the generated current persists for an unprecedented 400 ms, which is an unanticipated result.



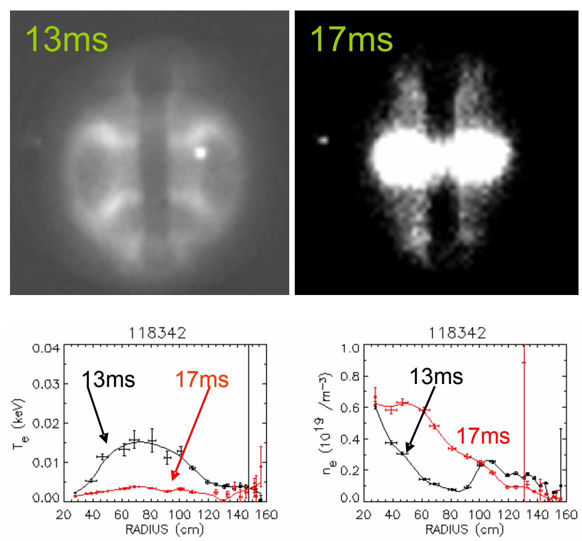


Figure 1: The plasma current and capacitor bank voltage traces, fast camera images and the electron density and temperature profiles from Thomson scattering measurements for transient CHI discharges in NSTX.

The significance of these results are (a) demonstration of the process in a vessel volume thirty times larger than HIT-II on a size scale more comparable to a reactor, (b) a remarkable multiplication factor of 60 between the injected current and the achieved toroidal current, compared to six in previous experiments, and (c) significantly more detailed experimental measurements, including, for the first time, fast time-scale visible imaging of the entire process that shows discharge formation, disconnection from the injector and the reconnection of magnetic field lines to form closed flux. Results from these and other new experiments in NSTX will be presented.

[1] R. Raman, T.R. Jarboe, B.A. Nelson *et al.*, "Demonstration of plasma startup by coaxial helicity injection," Phys Rev. Lett. **90** 075005 (2003)

*Work supported by US DOE contracts DE-FG03-9ER54519 and DE-AC02-76CH03073.