EX-W

Demonstration of 200 kA CHI Startup Current Coupling to Transformer Drive on NSTX

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Toroidal magnetic configurations based on the tokamak concept might be simplified and their cost reduced if the central solenoid, which is a large engineering component in conventional tokamak reactor designs could be eliminated. The central solenoid also requires extensive neutron shielding and places a lower limit on the achievable aspect ratio in reactor tokamak designs. Solenoid-free startup is a critical issue for future spherical torii (STs) designs, as the central-axis region is limited both physically and by the nuclear environment.

Transient Coaxial Helicity Injection (CHI) initiated discharges in NSTX [1] have increased the peak currents achieved to up to 300 kA for the first time, and when these discharges are coupled to induction, up to 200 kA additional current over inductive-only operation has been produced. CHI in NSTX has shown to be energetically quite efficient, producing a plasma current of about 10 A/Joule of capacitor bank energy. In addition, for the first time, the CHI-produced toroidal current that couples to induction continues to increase with the energy supplied by the CHI power supply at otherwise similar values of the injector flux, indicating the potential for substantial current generation capability by CHI in NSTX and in future toroidal devices.

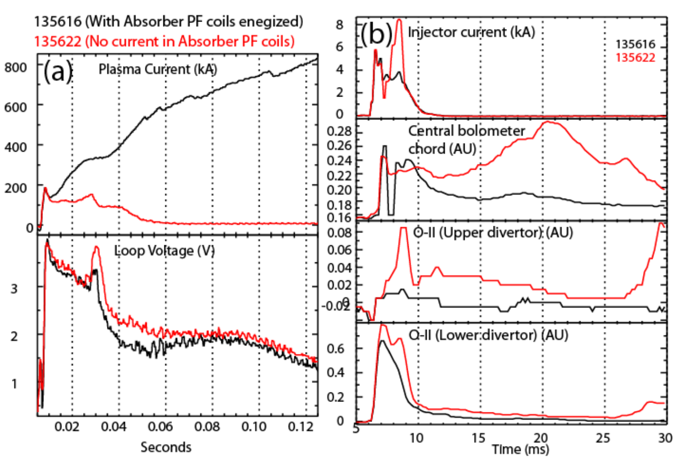

Figure 1: Shown are (a) the plasma current and pre-programmed loop voltage for two discharges. Discharge 135622 is a reference discharge in which the absorber PF coils were not energized. In discharge 135616 the absorber PF coils provided a buffer flux to the evolving CHI discharge. Also shown are (b) the injector current, signal from a central chord bolometer, the upper and lower divertor O-II signals.

Previously, up to 50 kA of toroidal plasma current produced by the non-inductive method of CHI was successfully coupled to inductive ramp-up in NSTX. However, in these experiments, the CHI current that could be successfully coupled was limited by impurity production in the divertor region and the occurrence of absorber arcs (*i.e.* parasitic discharges across the insulating gap in the upper divertor). In FY2009, extensive conditioning of the divertor plates that serve as the electrodes for the CHI discharge greatly reduced impurity production during CHI. This was accomplished by running discharges between the divertor electrodes for up to 0.4 s using a rectifier power supply. Further, by energizing, for the first time, the axisymmetric absorber field-nulling coils [2] located near the upper divertor in NSTX, the absorber arcs could be delayed or suppressed. It was found that a rapid ramp of the absorber-nulling coil current could prevent the rapidly expanding CHI plasma from approaching the absorber gap and initiating an absorber arc. This is illustrated in Figure 1. Discharge 135622, which has no current in the absorber poloidal field coils, shows no coupling to induction for otherwise identical conditions. An examination of the injector current trace shows the characteristic spike at 9 ms indicative of the occurrence of an absorber arc, which is absent for the discharge with the buffer flux applied. On the other hand, in the discharge 135616 with buffer flux applied, the CHI-produced discharge couples well to induction and ramps up to 800 kA.

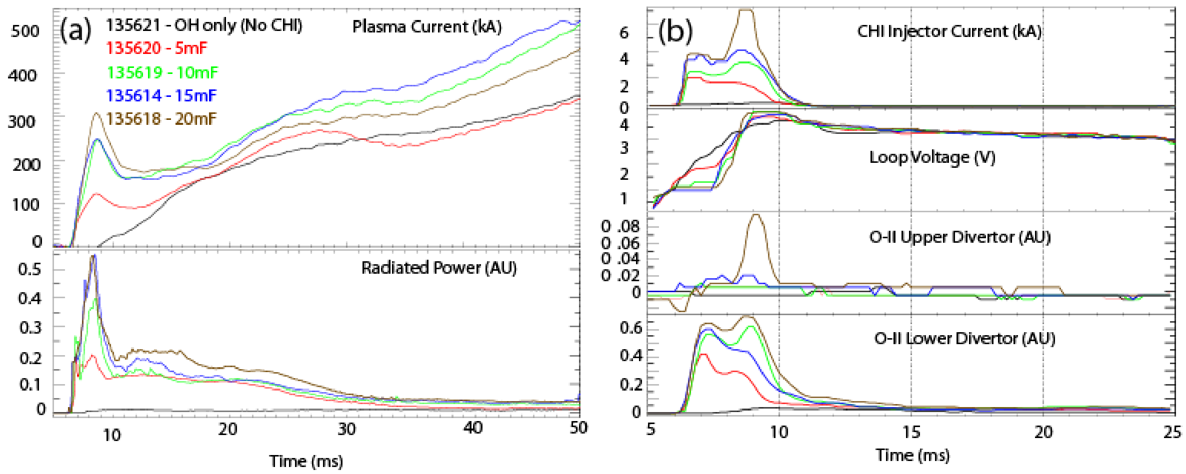

Figure 2: (a) Shown are plasma current and radiated power traces from a scan in which the size of the CHI capacitor bank power supply was increased from 5 to 20 mF. Discharge 135621 is a reference inductive-only discharge. (b) CHI injector current and spectroscopic traces for the four discharges.

In addition to these combined improvements, the use of lithium evaporative coatings using the LiTER system [3] increased the current at the hand-off from CHI to induction to nearly 200 kA. Furthermore, later in the inductive ramp-up, the discharges with CHI applied reached significantly higher plasma current than discharges with only the inductive loop voltage applied. These are shown in Figure 2. For example, in discharges with identical programming of the central solenoid current, the plasma current at t = 50 ms increased from 340 kA with induction only to 520 kA with CHI. This represents a poloidal flux saving equivalent to 180 kA of plasma current which is ~25% of the flat-top current of 700 kA typical of long-pulse scenarios on NSTX. This result was obtained utilizing only 30% of the energy available from the CHI capacitor bank (15 mF of the available 50 mF). Discharge 135618 with four capacitors reached an initial peak of 300 kA, which is a record for transient CHI-started discharges in a ST or tokamak. The initial stored capacitor bank energy is 27 kJ, which is quite modest. Although this too subsequently shows better performance than the inductive-only discharge, it is not as good as that for the two and three capacitor cases. The reason for this is seen in Figure 2(b), which shows that the constant value of buffer field that was used for all cases was inadequate for this higher current discharge as an absorber arc occurred and consequently there was additional impurity influx. These results indicate that more buffer flux is required for the higher current CHI discharges but in these experiments, the absorber PF coil currents were limited by their power supplies.

These results represent a factor of four improvement in the magnitude of current that was ramped up by induction, a factor of three increase in the initial start-up current, and the first results demonstrating flux savings in NSTX. The CHI-started discharge, when coupled to induction produces about 60% more current than the comparison inductive-only case. These results confirm that CHI could be an important tool for non-inductive start-up in next-step STs.

References:
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