Non-inductive Plasma Start-up in NSTX Using Transient CHI

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Transient Coaxial Helicity Injection (CHI) in the National Spherical Torus Experiment (NSTX) has generated toroidal current on closed flux surfaces without the use of the central solenoid. When induction from the solenoid was added, CHI initiated discharges in NSTX achieved 1 MA of plasma current using 65% of the solenoid flux of standard induction-only discharges. In addition, the CHI-initiated discharges have lower density and a low normalized internal plasma inductance of 0.35, as desired for achieving advanced scenarios. The Tokamak Simulation Code (TSC) has now been used to understand the scaling of CHI generated toroidal current with variations in the external toroidal field and injector flux. These simulations show favorable scaling of the CHI start-up process with increasing machine size. These results from NSTX imply a current generation potential in excess of 500 kA in the NSTX-U currently under construction. Both conventional aspect ratio tokamaks and spherical tokamaks (STs) have generally relied on a central solenoid to generate the initial plasma current and then to sustain that current against resistive dissipation. However, in a steady-state reactor, induction alone cannot be used for plasma current sustainment. The inclusion of a central solenoid in a tokamak to provide plasma startup limits the minimum aspect ratio and increases the device complexity. For reactors based on the ST concept, elimination of the central solenoid is essential, making alternate methods for plasma start-up necessary for such a reactor. CHI is implemented in NSTX by driving current from an external source along field lines that connect the inner and outer lower divertor plates. When compared to standard discharges in NSTX that are initiated inductively, the CHI assisted discharges have much lower plasma internal inductance and their line-integral electron density is about one third that of the standard NSTX discharges. As a result of the lower inductance, the CHI started discharges also have a higher plasma elongation for a similar programming of the NSTX shaping coils. Operational experience has shown that for the standard inductive startup in NSTX, both the higher plasma density and the slower current ramp rates are required to avoid mhd instability during the current ramp. The lower internal inductance of CHI generated discharges is related to the hollow electron temperature profile, which is a characteristic of the CHI start-up process. This causes more of the current to flow in the outer region resulting in lower inductance plasma. This is advantageous for producing shaped equilibria because the current flowing in the plasma is effectively closer to the currents in the external equilibrium control coils. Many advanced operating modes for tokamaks strive to maintain a hollow current profile throughout the discharge both to reduce thermal transport and to maintain macroscopic plasma stability. That CHI is able to provide an initial current profile similar to that which is achieved in conventional tokamaks through the use of high-power auxiliary heating, in conjunction with lower densities should benefit advanced scenario operations. The NSTX is now undergoing a major upgrade (NSTX-U) to increase the capabilities of its toroidal and poloidal field coils and to add a second neutral beam line. Analysis of the NSTX results shows that the amount of closed-flux current generated by CHI is closely related to the initially applied injector flux. On NSTX-U the available injector flux is about 340 mWb, considerably exceeding the 80 mWb in NSTX. Simulations with the TSC projects that it should be possible to generate 500 kA of closed-flux current with CHI in NSTX-U. At this current, the second more tangentially injecting neutral beam should be capable of providing sufficient current drive to ramp-up the plasma current. The results from TSC simulations show that CHI could be an important tool for non-inductive start-up in next-step STs. This work was supported by U.S. DOE contracts DE-FG02-99ER54519 and DE-AC02-09CH11466.