DPP13-2013-000785

Abstract for an Invited Paper
for the DPP13 Meeting of
the American Physical Society

Physics of fast flux closure in coaxial helicity injection experiments in NSTX

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Advancing toward non-inductive start-up and current drive for tokamaks, a solenoid-free plasma start-up method called transient coaxial helicity injection (CHI), first developed on the small HIT-II device, has been extended to the large NSTX device, in which up to 300kA of plasma current has been generated. Unlike driven CHI (edge current drive) where non-axisymmetric MHD activity relaxes the current inward, in transient CHI only axisymmetric reconnection generates a high quality closed flux start-up equilibrium, as found in resistive MHD simulations of CHI in NSTX using the NIMROD code (nimrodteam.org). Closed flux surfaces during simulations of transient CHI can be explained through 2-D Sweet-Parker type reconnection. Non-axisymmetric 3-D modes do not appear to play a dominant role at present experimental parameters. Our simulations have used fixed boundary flux (including NSTX poloidal coil currents) and the NSTX experimental geometry. We find that, as in the experiment, an X point followed by a fairly large volume of closed flux surfaces is rapidly formed; within 0.5 ms after the injector voltage and current begin to rapidly decrease. These direct numerical simulations reveal the fundamental mechanism for the reconnection process in transient CHI. Through direct numerical calculations, we find that as the injector voltage is turned off, the fields lines tend to untwist in the toroidal direction and magnetic field compression exerts a radial JXB force to bring oppositely directed field lines closer together to reconnect. A hierarchy of models from a zero pressure model to simulations with temperature evolution, allow us a full and more detailed understanding of the reconnection and closed flux surfaces. We find that magnetic fluxes are only reconnected at low magnetic diffusivity (high Lundquist number). In these simulations, narrow current layers form and cause the flux to close at a fast time scale when pinch flows are generated near the injector flux foot-print location.

This work has been done in collaboration with R. Raman, E. B. Hooper and C. R. Sovinec. Supported by DOE-FG02-12ER55115.