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Key to the development of the spherical torus (ST) concept is the successful demonstration of a plasma current initiation method that does not rely on poloidal field (PF) coils located in the central solenoid (CS) region ("solenoid-less") [1]. Recent experiments in DIII-D have produced up to 170 kA of plasma current in such a configuration with electron cyclotron heating (ECH) to assist in breakdown and impurity burn-through. Application of neutral beam current drive (NBCD), electron cyclotron current drive (ECCD) and fast wave current drive (FWCD) in similar scenarios, but using a conventional solenoidal startup, has elucidated present DIII-D potential for driving noninductive current in the limited, L-mode plasma typical of that currently generated during solenoid-less startup. The focus of DIII-D experiments in 2009-10 was to maximize the solenoid-less generated plasma current, and to determine DIII-D's present non-inductive current drive capabilities in plasma configurations similar to the solenoid-less. Figure 1 shows the geometry and coils used in the campaign.

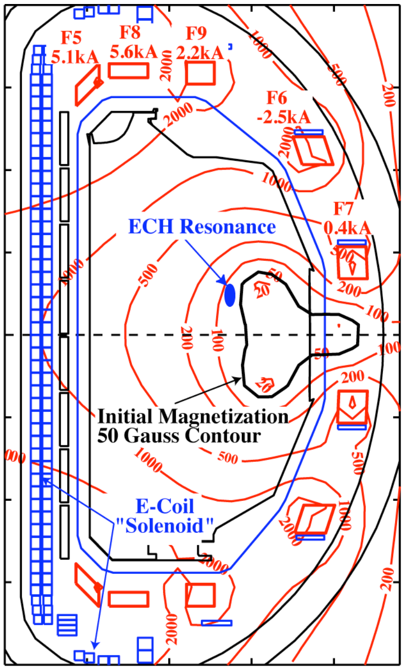

Fig. 1. DIII-D geometry for solelnodless campaign. Shown (red) are divertor coils (F5, F8, F9) and outer coils (F6, F7) used for 2010 solenoidless campaign along with PF currents prior to plasma initiation. Contours of poloidal magnetic field at this time are shown (red) with the 50 G level in black. Also shown are the ECH resonance and the E-coil (perfect solenoid) used for solenoid–to–non-inductive current drive experiments.

Figure 2 shows plasma current time traces for two of the scenarios developed for the solenoid-less configuration. Peak current of 170 kA was achieved using the most aggressive scenario possible, in which flux generation was restricted by divertor coil current or power supply limits. ECH power levels of 2 MW were required to achieve pre-ionization and burn through. Efficiency of flux conversion to plasma current is only slightly degraded in these scenarios relative to normal solenoid startup of DIII-D. Preliminary testing of NBCD was done in a more conservative scenario generating 150 kA (blue trace), but significant radial plasma motion made it impossible to quantify CD effectiveness. Early experiments were generated using open loop coil currents for control, but subsequent experiments employed both radial and vertical position control. Figure 3 shows the evolution of the plasma boundary typical of these scenarios, from its outside formation location to an upper single-null diverted configuration at peak plasma current. Subsequent equilbria become inside limited as currents in the divertor coils go to zero.

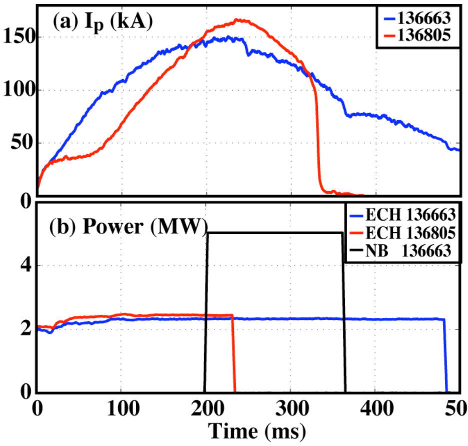

Fig. 2. Plasma current (a) and injected power (b) traces for the solenoid-less campaign. Peak current of 170 kA was achieved in shot 136805 (red). Low-level (2 source) NB injection was tested in a less aggressive shot (136663) but CD discrimination was lacking due to the open loop nature of radial position control.

Separate experiments to quantify the present low current non-inductive drive capability of DIII-D in a well controlled, limited plasma are underway using a conventional solenoid generated startup with handoff to NBCD, ECCD and FWCD. Early experiments in DIII-D using hydrogen beams into helium plasma with a diverted, H-mode plasma showed sustained NBCD current of 340 kA following conventional CS initiation of the

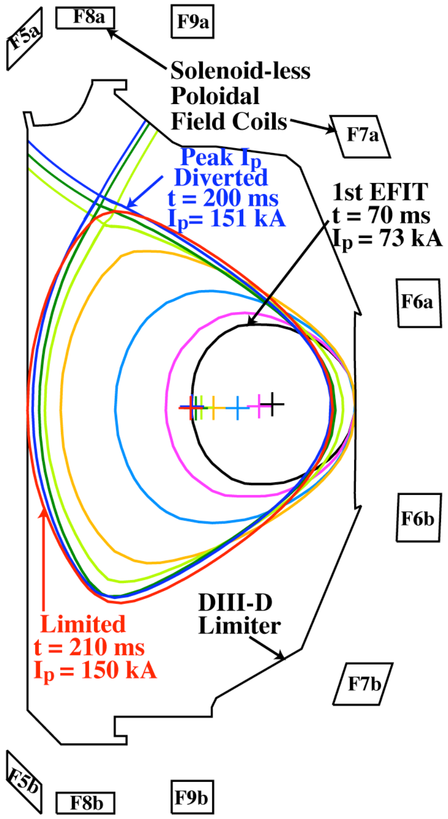

Fig. 3. Plasma separatrix shape change from initial equilibrium to peak plasma current. Plasma is initiated at the outer extreme of the device and evolves inward to become diverted and finally insides limited as the current decays.

plasma [2]. Later results from DIII-D indicated that fully stationary NBCD is very dependent on power and density conditions [3]. Relative to these earlier experiments substantial ECCD and fast wave (FW) power are now available for scenario development. However, only six co-NB sources are available now in DIII-D compared to eight sources used in earlier experiments. In addition, previous experiments focused on H-mode, diverted plasmas [2], while the current campaign is studying limited, L-mode plasmas, which are more characteristic of solenoid-less startup in DIII-D. Experiments are underway to determine the minimum current required for steady state non-inductive sustainment based on an optimum mix of NB, EC, and FW current drive, as well as bootstrap current contribution. Preliminary results indicate that with the present DIII-D configuration, low current, noninductive steady state operation is difficult in an L-mode, limited plasma. Further studies are expected to explore solenoid-less divertor operation and potential noninductive drive methods in diverted, H-mode plasma

Historically, many machines have explored solenoid-less startup. MAST has produced 400 kA of plasma current using inside coils [4], but such coils would be problematic in a reactor environment. JT-60U has shown nearly solenoid-less operation with small flux provided by a solenoidal coil, with sustainment from NB and lower hybrid current drive [5]. Additionally, JT-60U achieved 100 kA using only outside coils and strong ECH, but did not couple this to non-inductive current drive [6]. The solenoid-less configuration developed here is expected to be applicable to other devices and the CD studies provide a basis for further development of solenoid-less to fully non-inductive driven plasma.

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