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Non-Inductive Plasma Start-up Experiments on the TST-2 Spherical Tokamak Using Waves in the Lower-Hybrid Frequency Range

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Although the spherical tokamak (ST) has the attractiveness of good stability at high beta, it is presently considered impractical to realize a compact ST fusion reactor unless the central solenoid can be eliminated. Non-inductive plasma current start-up and sustainment by waves in the lower-hybrid (LH) frequency range (200 MHz) have been studied on the TST-2 spherical tokamak (major radius R_0 = 0.38 m, minor radius a = 0.25 m, toroidal magnetic field B_t = 0.3 T, plasma current I_p = 0.14 MA) using three types of antenna: 11-element inductively-coupled combline (ICC) antenna, dielectric loaded 4-waveguide array (GRILL) antenna, and 13-element capacitively-coupled combline (CCC) antenna. The maximum plasma currents of 15 kA, 10 kA and 12 kA were achieved, respectively. The GRILL antenna was used to determine the optimum range of parallel index of refraction, 1 < n_para <5. The highest current drive figure of merit, eta_CD = n_e*I_p*R_0 / P_RF where n_e is the electron density and P_RF is the injected RF power, was achieved by CCC. This antenna has the advantage of exciting a uni-directional LH wave with high directionality and a sharp n_para spectrum. Up to about 3 kA, the plasma current can be sustained even when waves were excited in the anti-current-drive direction. At higher I_p, current is carried by high energy electrons accelerated by waves. Both X-ray response to P_RF modulation and orbit calculations indicate significant orbit losses of high energy electrons, especially those created near the plasma edge. The efficiency of current drive should improve by reducing prompt orbit losses. Operation at higher B_t moves the wave damping region to the plasma core by improving wave accessibility, whereas higher I_p reduces the orbit width and higher n_e prevents electrons to be accelerated to too high energy. However, since a density limit above which the current drive efficiency deteriorates is observed experimentally, the density must be kept below this limit. It is found experimentally that the injection of ECH power is useful to prevent the density from increasing too much. In addition, a further improvement of the n_para spectrum of the LH wave excited by the CCC antenna should be possible by reducing the electron density in front of the antenna.

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