Evidence for Magnetic Relaxation in Coaxial Helicity Injection Discharges in the HIT–II Spherical Torus

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Experiments in central-solenoid-free initiation and ramp-up of plasma current

Coaxial Helicity Injection (CHI) is a noninductive current drive technique which has been used for discharge startup and sustainment in both Spherical Tokamaks (STs) and spheromaks. CHI injects magnetic helicity into these plasmas by applying voltage to a pair of flux-connected coaxial electrodes, and driving current in the resistive plasma edge. Recent CHI studies using the Helicity Injected Torus device (HIT–II[1]) have produced discharges with toroidal plasma currents up to 350 kA. The plasma current in these low-field discharges is much greater than the corresponding product of injector current with edge safety factor, indicating that the measured toroidal current cannot be entirely due to "wrap-up" of injector current. Direct measurements using an internal magnetic probe array show a total poloidal flux in the confined plasma significantly greater than the vacuum injector flux, confirming both the unambiguous presence of a closed-flux core region and the generation of poloidal flux through magnetic relaxation. The key innovation for producing these discharges is the high ratio of CHI injector current to toroidal field current. This condition for current buildup and flux amplification can be restated as having the dimensionless product $\lambda_{\rm INJ}d$ greater than 0.3, where d is the effective distance between the CHI electrodes and $\lambda_{\rm INJ}$ is the inverse magnetic scale length associated with the CHI injector (defined as $\mu_0 I_{\rm INJ}/\psi_{\rm INJ}$, where $I_{\rm INJ}$ is the injector current and $\psi_{\rm INJ}$ is the poloidal injector flux connecting the electrodes). The fact that $\lambda_{\rm INJ}d$ must exceed a critical value is understood in terms of two competing processes: (1) reconnection near the X-point generating closed poloidal flux and (2) resistive decay of the closed-flux current, where the critical value of $\lambda_{\rm INJ}d \approx 0.3$ corresponds to a rate of relaxation approximately equal to that of resistive decay. Higher values of $\lambda_{\rm INJ}d$ correspond to more magnetic field pitch in the injector region, and thus even higher rates of magnetic relaxation[2].

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[1] Redd *et al.*, Phys. Plasmas **9**, 2006 (2002)
[2] Ono *et al.*, Phys. Fluids B **5**, 3691 (1993)