Non-inductive current start-up and ramp-up by X-wave ECCD in fusion tokamaks

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Some improvement in engineering of tokamak reactors would be possible, if a hot plasma with T_e up to a few keV and I_p up to a few hundred kilo amperes could be non-inductively built up prior to inductive current ramp-up to a full current for fusion ignition and burning. From the view point of reactor engineering, electron cyclotron (EC) heating and current drive (ECH/ECCD) is attractive for the non-inductive build up.

In a startup discharge, toroidal plasma current is initially low and all the plasma would be in open fields. As the current develops by ECH, a small closed flux surface would appear and then the current inside the surface would develop by ECCD. Eventually the discharge would develop into the tokamak stage, where whole the plasma is contained in large closed flux surfaces, and the plasma is heated with the current ramp-up by ECCD, and finally the goal of hot plasma buildup would be accomplished. It has been shown that oblique X-waves are useful for ECH/ECCD for every stage of the discharge and it was suggested that an injection power of Prf~4 MW could build up a hot plasma with the toroidal plasma current of I_p~200kA, n_e~$1.2 \times 10^{19} m^{-3}$, T_e~2keV, a=1 m and R_0=5.1m in ITER [1].

As the electron temperature T_e increases into keV range, however, plasma conductivity becomes very high and the return current driven by the self-induction voltage from EC driven current would hamper the current ramp-up. Here we study the current ramp-up for an ITER case using a current circuit model for the ECCD driven current and the return current. The circuit equation is coupled with the ECCD efficiency equation [2] and the ITERL-97P energy confinement scaling [3]. Numerical study for various cases elucidates key points for efficient current ramp-up in keV range plasmas.

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[2] C.F.F. Karney and N.J. Fisch, Phys. Fluids, **29** (1986)180.
[3] S.M. Kaye and ITER Confinement Database Working Group Nucl. Fusion **37**(1997) 1303.