# Plasma Current Startup without the Ohmic Solenoid in JT-60U and Implications for ST Reactors

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In conventional tokamak operation, Ohmic heating (OH) solenoid is used to ramp up the plasma current inductively. However, it is not possible to accommodate an OH solenoid in an ST reactor. Therefore, plasma current startup without the OH solenoid is a major issue. In JT-60U, successful startup of the plasma current by a combination of induction by outer poloidal field (PF) coils, heating and noninductive current drive, and bootstrap current was demonstrated. In addition, successful transition to a high-performance advanced tokamak plasma with high beta, high confinement, and high bootstrap fraction was also demonstrated.

The rampup scenario consisted of three phases:
(1) Plasma startup by strong preionization by EC and/or LH and inductive rampup by outer PF coils, starting from a negative vertical field (in the opposite direction to that required for equilibrium).
(2) Noninductive current overdrive by LHCD, combined with EC electron heating. Current rampup during this phase can decouple the poloidal flux supplied by the PF coils and the vertical field they provide.
(3) Transition to a bootstrap dominated steady-state phase. Intense neutral beam heating during this transition resulted in further plasma current rampup.

In the JT-60U experiment, 200 kA of current rampup was achieved in each of the three phases. The plasma generated by this scenario had a wide internal transport barrier (ITB) and an edge transport barrier (H mode). This plasma had $\beta_p = 3.6$, $\beta_N = 1.6$, $H_{H98y2} = 1.6$, and a bootstrap current fraction of at least 90%. This plasma had a plasma current of 600 kA and consequently the safety factor was high, with $q_{95} = 12.8$.

In this experiment, about 20% of the total poloidal flux was provided by the inner turns of the triangularity control coil. A proposal to test a similar plasma current rampup scenario by using only outer PF coils and heating will be discussed.

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