§45. A Study of Plasma Start-up in Spherical Tokamak Devices

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Key issues in spherical tokamak (ST) research are plasma current start-up and formation of the ST configuration without the use of a central solenoid (ohmic coil). Successful start-up, ST formation and sustainment have been achieved by injecting RF power to a configuration with a toroidal field and a weak vertical field. However, the current formation (i.e., current drive) mechanism and the ST formation mechanism are still not clearly understood. Especially, equilibrium reconstruction was performed for only one case, and the time evolution and the variation in different operations remain unknown. The mechanisms for ST formation and the features of the plasma should be identified to extrapolate present results to next step ST devices.

Equilibrium configurations were reconstructed through a least square fit of a parameterized equilibrium to the magnetic measurements of about 80 channels. In order to take into account finite current density and pressure gradient in the open field line region, a truncated equilibrium is used. In equilibrium calculation, the Grad-Shafranov equation is solved to satisfy the force balance in the plasma area including both the open and the closed field line region. Thus, the plasma satisfies the force balance in the normal direction of each magnetic surface. However, the flux functions such as pressure and the poloidal current are truncated to zero at parallel boundaries defined by the walls and the limiters. The plasma boundary is determined by the magnetic surface passing through the outboard limiter and top, bottom or inboard limiters. The last closed flux surface (LCFS) is determined in practice by the inboard limiter in these experiments and the region outside the LCFS is the open field line region.

A discharge consists of the following three phases; (i) the initial current formation phase, in which plasma current increases gradually, (ii) the current jump phase, which denotes a rapid increase in the current and which is accompanied by the formation of an ST configuration; and (iii) the current sustainment phase.

In Fig. 1, the reconstructed equilibrium configuration at the initial current formation phase and that at the current sustainment phase are compared.

The current in the initial current formation phase is relatively small, and no closed flux surface is formed. While p' term dominates the toroidal current, ff' term is negative, indicating diamagnetism (Fig 1. (b)). The contours of the current density make banana shapes along the outboard flux surface (Fig. 1 (c)). The inboard limiter and the top and the bottom boundaries form the truncated boundary.

The current jump is a phenomenon found in LATE, and observed in other experiments. It is a spontaneous transition from an open field line configuration to an ST configuration with closed flux surfaces. It is believed that the confinement of the current carrying particles is improved as soon as closed flux surfaces are formed. According to the equilibrium analysis, however, the initial closed flux surface appears when the rapid current increase (i.e., current jump) stopped. During a jump, the radius of the maximum current density shows only a slight change, indicating slow and gradual transition from an open field line configuration to a partly closed field line configuration. This is quite different from the violent transition (i.e., dynamics) seen in the merging or the coaxial helicity injection (CHI) start-up experiments. Thus, we cannot expect and could not observe ion heating due to magnetic reconnection.

After a current jump, closed flux surfaces exist and the plasma current is sustained (Fig. 1 (f)). The shape of the LCFS is characterized by a low elongation factor ~0.7. The central safety factor is q0 ~ 100. The fraction of the plasma current inside the LCFS to the total current is ~ 40 % at this time, and it increases gradually.

The equilibrium for a low frequency (2 MHz) RF sustained plasma is similar to EC sustained cases, suggesting that a pressure driven current dominates the current. The main feature of the RF sustained discharge is the large fluctuations, which often lead to a discharge termination.

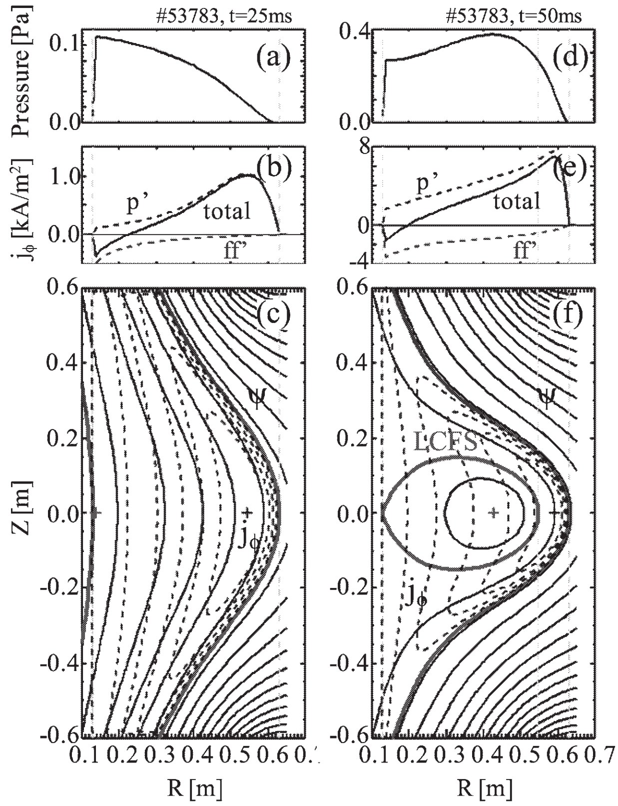

Fig. 1. Reconstructed equilibria at two times t=25 and 50 ms. Figs. (a), (d), show the midplane pressure profile, and Figs. (b), (e) show the toroidal current density profile. Figs. (c), (f) show the contours of the poloidal flux function and the current density.