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Formation of Closed Flux Surfaces in Reconnection Current Layer by Accelerated Electrons during Merging Start-up of Spherical Tokamak

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Spherical tokamak (ST) concept provides a potential for high-beta plasma confinement, however, it requires downsizing or removal of center solenoid (CS) coil because of restricted room in the central region. As one of candidates for CS-free start-up methods, combination of torus discharge by using external poloidal field coils and axial merging technique has been developed in the UTST experiment to establish an ST target plasma for neutral beam injection.

The merging method involves magnetic reconnection in which high-power energy conversion from magnetic to mostly ion kinetic/thermal energies takes place, but more efficient electron heating, which is supposed to be provided only inside the reconnection current layer, is required to apply the merging method to form an ST target plasma. In ST merging case, large toroidal magnetic field (TF) perpendicular to the reconnection magnetic field exists and changes the reconnection local and global behaviors. One of the unique features provided by the TF is electron direct acceleration along the TF by reconnection electric field. In the UTST experiment, soft X-ray emission burst was observed during the merging phase, indicating that energetic electrons were generated by the reconnection process with TF. Fast camera observation of reconnection region showed that ring-shaped emission regions where impurity ions were ionized/excited by accelerated electrons were formed near the reconnection X-point.

The accelerated electrons are expected to flow out quickly from the reconnection region, but detailed analysis of the camera image indicated that the electrons with high parallel velocity stayed much longer duration inside the current layer and thus they would achieve higher energy than those predicted in the classical reconnection model. Magnetic field and current density profiles were obtained by an internal magnetic probe array inserted inside the current layer. Since the accelerated electrons had high parallel (toroidal) velocity, they locally enhanced the toroidal current density and finally made a reversal of magnetic field in the vicinity of the current channel, which improved the electron confinement and thus provided higher electron heating efficiency during merging start-up of ST plasma.

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