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Control of Electron Acceleration Process during Merging Start-up of Spherical Tokamak

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We have demonstrated that the self-generated poloidal electric field, which reduces the electron acceleration efficiency in the spherical tokamak (ST) merging start-up, was successfully controlled by changing the inboard limiter condition. This result suggests that higher electron temperature ST could be formed by the merging start-up scheme with optimized conducting material structure that contacts the plasma.

Axial plasma merging is one of the ST start-up schemes without use of a center solenoid coil and is adopted in several ST experiments to achieve high performance discharge. The merging method is capable of forming high ion temperature ST plasma [A] due to magnetic reconnection process which converts magnetic energy to plasma kinetic/thermal energy. Since the duration of plasma heating and current drive provided by the merging process is limited within a short period (< 1 ms), the formed ST must be sustained by external heating/current drive methods, such as neutral beam and high frequency waves, which require sufficiently high electron temperature. Thus, electron heating process should also be included in the merging start-up. Direct acceleration of electrons along the magnetic field lines is a potential source for electron heating [B] because the reconnection process involved in the ST merging start-up proceeds under a strong toroidal (guide) magnetic field which is parallel to the reconnection electric field. However, self-generated electric field reduces the parallel electric field component and then the electron acceleration efficiency is largely degraded in the guide-field reconnection or tokamak breakdown at a null-point [C].

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In the UTST device 2, two ST plasmas are formed by use of external poloidal field coils and merge through magnetic reconnection on the midplane (Z = 0). Fig. 1 shows the schematic of the UTST central part together with the observed magnetic flux surfaces and soft X-ray (SXR, > 100 eV) emission profile during merging start-up. Intensive SXR emitted from energetic electrons was observed in the wide area of the inboard-side downstream region because the self-generated poloidal electric field could be suppressed by the conducting material (inboard limiter) that contacts the field line. In order to improve the electron acceleration efficiency, the effect of the limiter shape was investigated in this research. Two additional electrodes were installed (see Fig. 1) to modify the shape of the inboard-side limiter by connecting/disconnecting them (hereafter called CONN/DISC cases).

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Fig, 2 shows the waveforms of (a) plasma current, (b) toroidal electric field E_t at the X-point, and (c) axial electric field E_z measured by a pair of Langmuir probes at the inboard-side downstream region (E_t = 0.24 m, E_z = 0) with DISC (red) and CONN (blue) electrode conditions. The electrode connection did not affect the macroscopic ST plasma behavior such as plasma current, but largely modified the magnetic reconnection condition. The result that the CONN case showed weaker R than the DISC case apparently suggests that the electron direct acceleration is less effective in the CONN case, but the self-generated poloidal electric field also showed different trend in these two cases. As shown in Fig. 2(c), the DISC case showed that Z had similar waveform with E_t while its amplitude was about 20 times as large as E_z. This ratio is same as the ratio of the toroidal (guide) magnetic field to the axial (reconnected) magnetic field. On the other hand, E_t in the CONN case started to rise later than E_t because the connected electrodes suppressed the polarization.

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We evaluated the parallel components of the toroidal and axial electric fields by using the local toroidal/axial magnetic field amplitude. Fig. 3 (a) shows the time evolutions of the parallel components E_z and E_t at the inboard-side downstream region in the DISC case. The parallel component of Et consisted the parallel component of R while their signs are reversed, resulting in nearly cancelled condition of the parallel electric field. When the magnetic field lines in the downstream region contacted the disconnected electrodes, large potential difference more than 1 kV was observed between the two additional electrodes as shown in Fig. 3(b). Thus, it is expected that the self-generated electric field could be suppressed by connecting the electrodes. Fig. 3 (c) shows that $E_{t,\parallel} = E_t B_t/|B|$ in the CONN case started to rise later than $-E_{z,\parallel} = -E_z B_z/|B|$ with a certain delay determined by the period of the corresponding field lines contacting the connected electrodes. As shown in Fig. 4, the field lines contacted the electrodes at E_z = 9.47 and 9.49 ms but was detached at $-E_{z,\parallel}$ = 9.51 ms when the parallel electric field was roughly cancelled as shown in in Fig. 3(c). It is concluded that limiter shape modification will change the polarization condition in the inboard-side downstream region and be capable of improving the electron acceleration efficiency in the merging start-up of STs.

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