Transient and Intermittent Magnetic Reconnections in TS-3/4 Merging Experiments and Their Extension to UTST High-Beta ST Experiment

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The merging startup of spherical tokamak (ST) has been studied in the TS-3 device for its high-power reconnection heating/ startup without center-solenoid (CS) coil. Two STs with major radii R~0.2m (TS-3)[1] were collided and merged together in the axial direction by the help of compression force provided by external PF coils. The magnetic reconnection transformed the magnetic energy of reconnecting magnetic field first through the outflow energy finally to the thermal energy, increasing the plasma beta up to 30-50%,

A new finding is that the transient effect of magnetic reconnection causes the fast merging speed as well as the high-power heating, even if effective resistivity of the current sheet is as low as classical. Their heating energy increases significantly with their reconnection speed, because the heating is cased by the reconnection outflow. The plasma colliding (inflow) speed was varied from zero to 30% of the Alfven speed V_A using compression coil/ PF coil currents. When the inflow speed was slower than 0.05 V_A, the plasma inflow flux balanced with the outflow flux, indicating the quasi-steady reconnection (dB/dt~dn/dt~0) like the MRX experiment[2]. When the inflow speed exceeded 0.1-0.2V_A, the inflow flux exceeded the outflow flux in the early reconnection phase, causing clear pileup of plasma and magnetic flux in the current sheet. When the inflow speed was increased over 0.2V_A, two types of fast reconnection mechanisms were observed to appear in the late reconnection phase. When the gyro-radius ρ_i was relatively large, the fast inflow compressed the sheet width δ shorter than ρ_i, causing the anomalous increase in the effective current sheet resistivity and the reconnection speed[1]. A question is how the inflow speed increases if the fast inflow over-compresses the current sheet whose effective resistivity η is as low as the classical one η_{cl}. When the condition: $\delta >> \rho_i$ maintained $\eta \sim \eta_{cl}$, the inflow flux was observed to pileup around the current sheet, causing the rapid growth and peaking of the current sheet. When the flux pileup exceeded the critical limit, the sheet was ejected mechanically from the squeezed X-point area. The reconnection speed was relatively slow during the flux-pileup and became drastically fast during the ejection, in agreement with the solar corona observations[3]. The sheet ejection was found to occur twice or three times. if we increases the initial reconnecting flux sufficiently large. These facts indicate that the plasma inflow fluxes larger than the plasma outflow fluxes transformed the quasi-steady reconnection though the transient one, finally to the intermittent one under the low resistivity condition ($\rho_i << \delta$). It is concluded that the growth and ejection of current sheet both increase plasma inflow (reconnection speed) due to its mass accumulation and ejection, respectively.

Based on these results, the transient shaping effect of current sheet is concluded to makes the reconnection (and outflow) faster, even if the sheet resistivity stays as low as the classical one. We are now up-scaling the TS-3 device to a new ST device UTST (R~0.4m) for fusion-relevant application of reconnection heating. The mega-watt heating power of reconnection is expected to transform the initial low-beta ST to the high-beta (30-50%) ST within the short reconnection time..

[1] Y. Ono et al. Phys. Plasmas. 4, 1953 (1997); Y. Ono et al. Phys. Plasmas. 7, 1863 (2000).
[2] H. Ji, M. Yamada et al. Phys Rev. Lett. 80, 3256 (1998).
[3] T. Yokoyama, K. Shibata et al., Nature 375, 42 (1995).