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Impulsive Magnetic Reconnection in TS-3 and 4 Merging Experiments

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We have been investigating three types of fast / impulsive magnetic reconnection mechanisms: anomalous reisistvity, plasmoid (sheet) ejection and three-dimensional (3-D) reconnection consistently in TS-3 and TS-4 tokamak merging experiments.
The onset of anomalous reisistvity of current sheet makes the reconnection fast and impulsive. It was observed in wide operation regime, when the current sheet was compressed shorter than ion gyro-radius. The effective resistivity here was defined as electric field / current density at the X-point. We studied the critical thickness of current sheet that determines the onset of anomalous resistivity, such as ion gyroradius, ion skin depth, mean-free pass etc. We found that the current sheet resistivity increases when its thickness is compressed shorter than ion gyroradius, not the ion skin depth. This fact indicates that the ion meandering (gyro) motion is a key to explain the onset of anomalous resistivity. The magnetic fluctuation inside the sheet was observed to increase with the resistivity of current sheet.
The 3-D effect of magnetic reconnection was observed when two tokamak plasmas with low guide-field were over-compressed by external coils. Their merging speed was varied by acceleration and separation coil currents for artificial control of the reconnection inflow. The over-compression of two tokamaks caused the 3-D local deformation of current sheet, while their global stability were maintained. The toroidal asymmetry grew locally around the current sheet during the reconnection time and was annihilated right after the completion of merging. This 3-D effect was emphasized by high plasma inflow and low guide-field. The electron density measurement indicated that the 3-D deformation increased the plasma mass ejection from the current sheet. The local compression of current sheet thickness shorter than the ion gyro-radius triggered its anomalous resistivity, causing significant increase in the reconnection speed.
The current sheet dynamics have been observed when two tokamaks with high guide-field were over-compressed, revealing transient and intermittent reconnections. The reconnection inflow flux larger than the outflow flux caused rapid growth of current sheet, followed by sheet deformation and ejection. Under high guide-field, the sheet resistivity was almost classical due to the sheet thickness larger than ion gyroradius. Large inflow flux and low current-sheet dissipation caused flux pileup, indicating rapid growth of the current sheet. When the flux pileup exceeded a critical limit, the sheet was ejected mechanically from the squeezed X-point area. The reconnection (outflow) speed was slow during the flux pileup and was fast during the ejection, indicating that intermittent reconnection similar to the solar flare increased the averaged reconnection speed. Right after the ejection, the current sheet was often transformed into several current islands, suggesting that the island size comparable with ion gyrodasius increased the sheet resistivity as well as the reconnection speed.
These impulsive effects enable us to realize the fast reconnection as well as the high-power reconnection heating in those merging tokamak experiments. The fast reconnection causes fast reconnection outflow, causing significant ion heating (MW-class) of merging tokamaks. These facts lead us to a new pulsed merging formation of ultra-high-beta spherical tokamak (ST) in the new merging device UTST (University of Tokyo Spherical Tokamak) with 0.7MW Neutral Beam Injection (NBI).

Keywords: magnetic reconnection, merging, impulsive reconnetion, 3-D reconnetion, current sheet, unsteady reconnection