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Reconnection Heating Experiments and Simulations for Torus Plasma Merging Startup

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A series of merging experiments: TS-3, TS-4 and MAST made clear the promising characteristics of reconnection heating for merging formation of high-beta spherical tokamak (ST) and field-reversed configuration (FRC). We found the reconnection outflow produces MW-class (<30MW in TS-3) ion heating power based on the findings:
(i) its ion heating energy that scales with square of the reconnecting magnetic field B_rec,
(ii) its energy loss lower than 10%,
(iii) its ion heating energy in the downstream 10 time larger than its electron heating energy at around X-point and
(iv) low dependence of ion heating on the guide (toroidal) field B_g.
Based on UK-Japan collaboration, we made the upscaled merging experiment in MAST and documented significant ion heating T_i˜1.2keV by increasing B_rec to 0.2T. Its ion heating ˜1.2keV and heating time 3-5ms are about four times higher and 50 times shorter than the conventional ion heating ˜0.3keV and heating time ˜200ms by the CS startup. An important finding is that the B_recˆ2 scaling law of reconnection heating energy was successfully extended over 1.2keV under n_e˜1.5x10ˆ19 [mˆ-3]. It depends just on B_rec and with little dependence on the guide (toroidal) magnetic field B_g. During the ST merging, B_rec and B_g are almost equal to poloidal field B_p and tortoidal field B_t, respectively but both components of B_p and B_t reconnect during the two spheromak merging with opposing B_t for FRC formation. Since the reconnection accelerated ions up to 70% of the Alfven speed, the ion velocity scales with B_rec, so that the T_i increment and the reconnection heating energy scale with B_recˆ2 under the constant n_e. It is noted that the reconnection heating does not depend on plasma size as long as the reconnection time is shorter than the plasma confinement time. This extended scaling law suggests that the merging startup will possibly realize the burning plasma temperature T_i >10 keV just by increasing B_rec over 0.6T. The merging/ reconnection heating will possibly provide a new direct route to burning plasma regimes without using any additional heating. This promising scaling leads us to new reconnection heating experiments for future direct access to burning plasma regime: TS-U in U. Tokyo and ST-40 in Tokamak Energy.

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