Ultra-High-Beta Spherical Tokamak Experiments in TS-3 and 4

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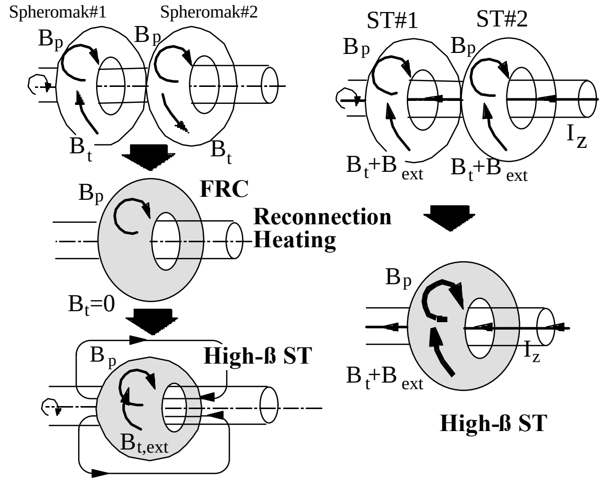
High-power heating (5-30MW) of magnetic reconnection has been used in TS-3 and 4 experiments to increase plasma beta of spherical tokamaks (STs) within a short reconnection time. As shown in Fig. 1(a), two spheromaks (ß=5-10%) with opposing toroidal field B_t were merged axially to produce an oblate FRC with ß=70-100%. Their magnetic reconnections converted the whole toroidal magnetic energy of the merging spheromaks into ion thermal energy of the produced FRC through ion acceleration effect of reconnected field lines. Then, applied external B_t transformed the FRC into an ultra-high-beta ST with ß=50-70%. This method eliminates a difficulty of forming a hollow current profile by fast ramp-up of ohmic heating (OH) coil current and provides us a new direct path to the second stable ST[1].



(a) Transformation of FRC (b) ST Merging

FIG. 1. Two formation methods of high-beta STs by use of merging/magnetic reconnection.

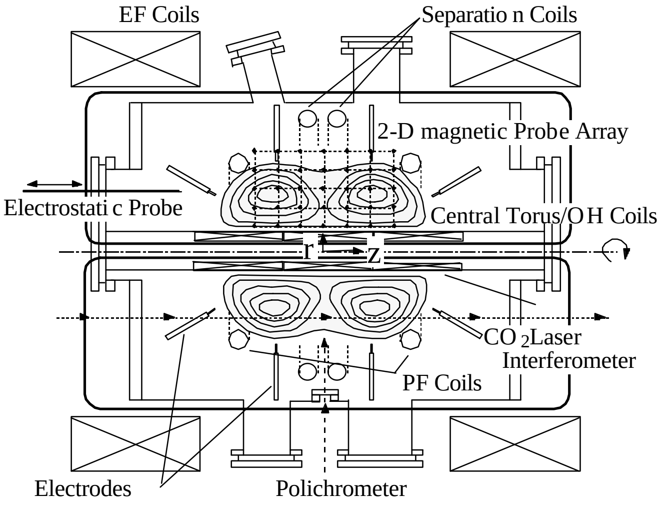


FIG. 2. TS-3 ST/FRC Merging Device (R=0.18-0.22m, R/a=1.5, B_0<2kG, T_i=10-200eV, T_e=10-40eV, n_e=2-10´10^{19}m^{-3}).

Figure 3 shows the high-beta ST formation process from merging spheromaks through FRC. Unlike the conventional paramagnetic ST, the produced ST had the toroidal field smaller than the applied $B_{t,ext}$, indicating formation of diamagnetic ST[1]. The hollow current profile of FRC was maintained during the equilibrium transition. Recently, the high-beta ST produced from the FRC was found to have an absolute minimum-B configuration in sharp contrast with the low-beta ST without B-minimum. Figure 4 shows |B| contours of the initial FRC, the produced high-beta ST and a low-beta ST for comparison. It was observed that the minimum-B area increased significantly around the center coil by applying the external toroidal field to the initial FRC.

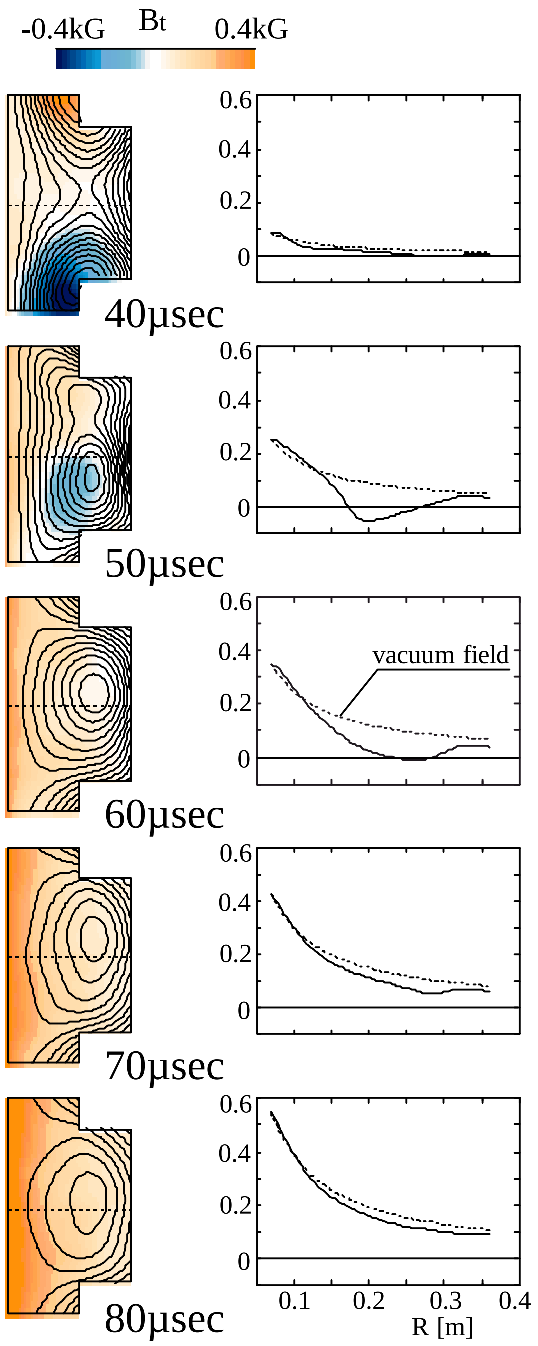


FIG. 3. Time evolutions of poloidal flux contour with B_t field amplitude and radial B_t profile during the ultra-high-beta ST formation.

The cohelicity merging/reconnection of two STs was also found useful to heat plasma ions and plasma beta by a factor of 2-5. We produced another high-beta ST using two merging low-beta STs as shown in Fig. 1(b). The ion heating effect of magnetic reconnection converted a part of poloidal magnetic energy of the low-beta STs into ion thermal energy of the high-beta ST. Consequently, formations of the high-beta STs with a variety of pressure and q profiles revealed their stability boundaries for the ballooning mode and possible ballooning collapses.

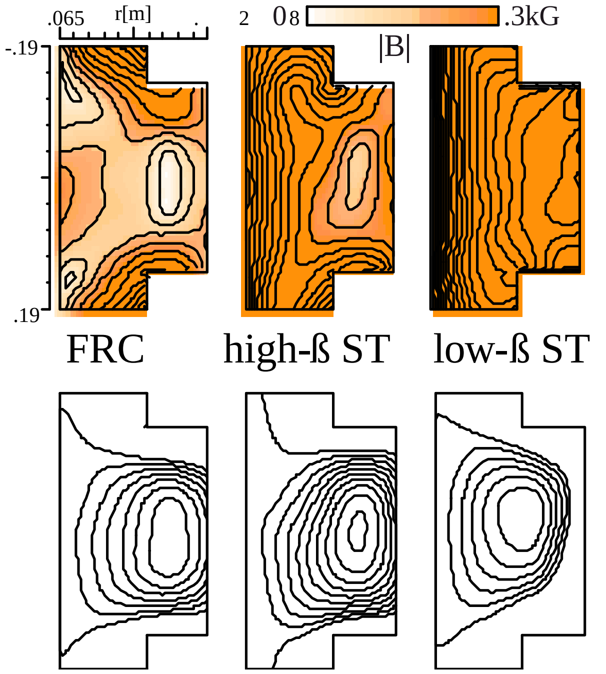


FIG. 4. |B| and poloidal flux contours of the FRC, the ultra-high-beta ST and the low-beta ST.

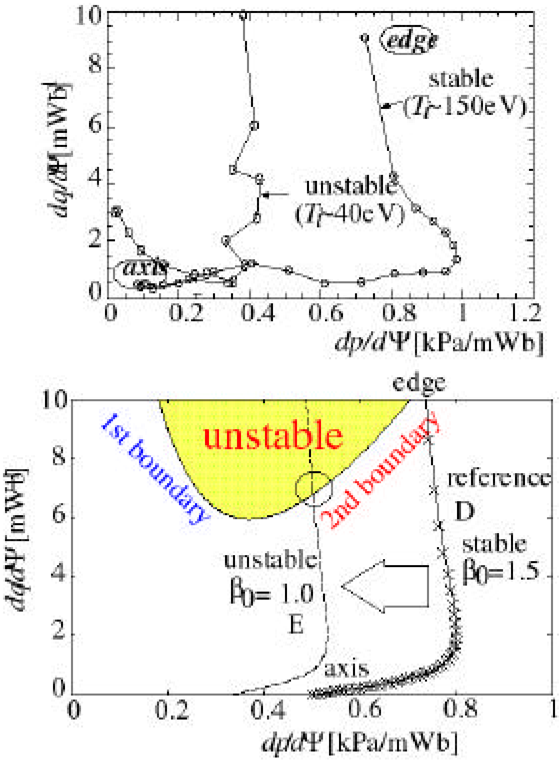


FIG. 5. q_y-p_y profiles of high-beta (stable) and medium-beta (unstable) STs produced from FRCs (upper) and their stability analyses using the BALOO code.

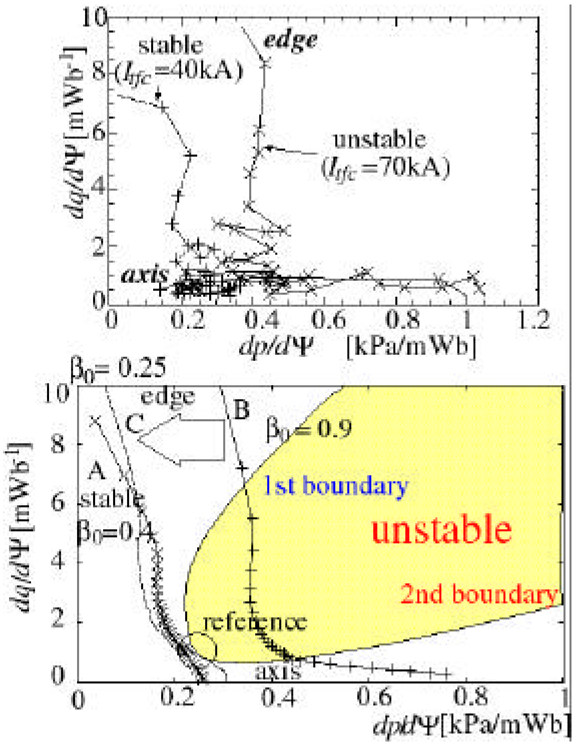


FIG. 6. q_y-p_y profiles of low-beta (stable) and high-beta (unstable) STs produced from cohelicity merging STs (upper) and their stability analyses using the BALOO code.

Figure 5 (upper) shows the q_ψ-p_ψ diagram of the high-beta and medium beta STs produced from FRCs. The high-beta ST with ion temperature $T_i \approx 150$eV had maximum pressure gradient and magnetic shear in the periphery and was maintained stable over 200μsec. On the other hand, the medium-beta ST was observed to collapse within 20μsec due to high-n ($n>8$) localized modes. As shown in Fig. 5 (lower), our stability analysis by the BALOO code indicated that the high-beta ST was located in the second stability regime of the ballooning mode and that the other medium-beta ST entered its unstable regime through the second-stability boundary.

Figure 6 (upper) shows the q_ψ-p_ψ diagram of the medium-beta and low-beta STs produced by cohelicity merging STs. The low-beta ST with maximum pressure gradient in the core was maintained stable, while the medium-beta ST collapsed due to high-n modes. As shown in Fig. 6 (lower), our stability analysis by the BALOO code indicated that the low-beta ST was located in the first stability regime of the ballooning mode and that the other medium-beta ST entered its unstable regime through the first-stability boundary.

Under the present experimental condition, the high-n ballooning mode was found the most dangerous instability for those high-beta STs produced by the merging / reconnection. A series of experiments indicates close relationship between FRCs and high-beta STs, leading us to a new boundary research between FRCs, STs and spheromaks in the upgraded merging experiment TS-4 with R=0.5m, A=1.2 and I<0.3MA.

[1] Y. Ono and M. Inomoto, Phys. Plasmas 7, (2000), p. 1863.