§ 26. Present Status and Future Prospect of Spherical Torus

Ono, Y., Takase, Y., Nagayama, Y., Maekawa, T., Nagata, M., Nishio, S., Nishitani, Y., Tobita, K., Okano, K., Mizuguchi, N., Mitarai, O., Katsurai, M. (Univ. Tokyo, NIFS, Kyoto Univ., Himeji Inst. Tech., JAERI, et al.)

The spherical torus (ST) has received increased attention due to the compatibility achieved between high-beta and a long confinement time. Several important steps for ST development was made in Japan, for example the first ST experiment at Tohoku university and merging / reconnection startup and advanced RF current drive at University of Tokyo, the RF startup at Kyoto University, many helicity injection experiment at Himeji Inst. Tech. and outstanding ST reactor studies at JAERI and NIFS. However, the MA class ST experiments: NSTX and MAST ware fist constructed in USA and United Kingdom and their large amount of budget and manpower are leading the largest class ST experiment in the world. An important question is how we Japanese fusion community should plan our future ST research. Objects of this workshop are to overview the present status of ST research and find its future prospect. Major researches are as follows:
(1) present status of high beta spherical torus confinements, (2) major achievements of ST research and its future prospect, (3)beta-limit of ST confimeent, (4) low-q limit of ST confimeent, (5) steady operation of ST reactor, (6) stability and relaxation of ST, (7) confinement properties of ST, (8) reactor designs suitable for ST.

The high beta ST study is one example of major workshop achievements. In addition to the high normalized current I/aB achievable at a low aspect ratio, an important advantage of this high-beta ST is its direct access to second stability for ideal ballooning modes. The mega-ampere class experiments, NSTX and MAST, renewed the record beta values up to b_T~35%, increasing confinement time up to t_E~0.1sec. Small-scale experiments produced the second-stable STs with diamagnetic toroidal field/ absolute minimum-B by transforming oblate FRCs. Major issues for the second stable STs are achieving a stable startup / profile control for kink and ballooning stabilities and a concrete approach to high-ratio pressure driven currents. Novel formations of ultra-high-beta ST have been developed in the TS-3 device by use of high power heating of merging/reconnection. As shown in Fig. 1, two types of merging were used for high-beta ST startup: (a) two STs were merged together to build up the plasma beta, (b) an oblate FRC was formed by merging of two spheromaks with opposing toroidal field B_t and was transformed into an ultra-high-ß ST by applying external B_t. These unique methods enabled us to explore unknown ultra-high beta (50-70%) regime of STs and also to vary current / pressure profiles (hollowness or broadness) of high-beta STs. Note that these merging provided significant heating power (1-30MW in TS-3) within short reconnection time (<confinement time) and that their electrodeless ST startup and axisymmetric merging have significant advantages over the present CHI startup.

Figure 2 shows the toroidal beta β_T of the STs by merging (a)(b) and single low-beta STs as a function of the Troyon beta limit I/aB_t. The single STs (no merging) have $\beta_T \approx 0$-0.15 almost equal to those of START. In the merging (a), ion acceleration effect of magnetic reconnection converted the a part of poloidal magnetic energy of merging ST into ion thermal energy ($T_i \approx 100$eV>>$T_e \approx 10$eV) of the produced ST, quickly increasing β_T up to 5-9. The merging (b) converted whole toroidal magnetic energy of spheromaks ($\beta_T \approx 0.1$, $T_i \approx T_e \approx 10$eV) into ion thermal energy ($T_i \approx 200$eV>>$T_e \approx 10$eV) of FRCs and the fast rump-up of external toroidal field transformed it into the high-beta ST with $\beta_T \approx 0.4$-1, $T_i \approx 150$eV>>$T_e \approx 20$eV. Its normalized beta β_N increased up to 17, exploring the new regime of high-beta ST experiment.

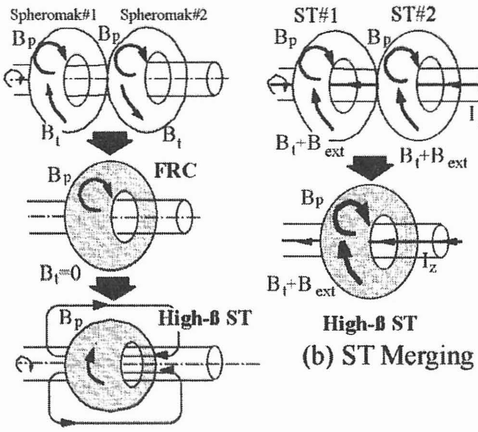

Fig. 1. Three types of high-beta ST formations: (a) transformation of FRC, (b) merging STs, (c) multiple ST merging, and (d) electrodeless merging using X-point ST formation.

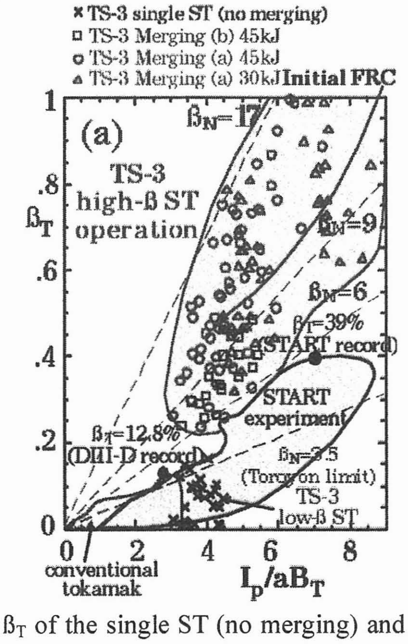

Fig. 2(a) β_T of the single ST (no merging) and high-beta STs produced by merging (a) and (b) as a function of I/aB_t,