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# Active Stabilization of FRCs by Intermittent Merging of Counter-Helicity Spheromaks in TS-3 and TS-4 Merging Experiments
# TS-3・TS-4装置を用いた異極性スフェロマックの連続合体によるFRCの安定化


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Since 1990, an efficient formation method of a field-reversed configuration (FRC) has been developed in the TS-3 merging experiment using two merging spheromaks with opposing toroidal field. This counterhelicity reconnection transforms two force-free ($\beta$ = 5-10%) spheromaks into an oblate FRC with $\beta$ = 70-100%, exploring the oblate FRC in large size-parameter (s) regime (<20). Slingshot and spontaneous formation of toroidal flow was measured during the FRC merging formation in TS-3 and TS-4 experiments. We found that this shear-flow produced by the sling-shot motion saturates the n=1 tilt instability for FRCs by transforming the n = 1 mode into the n = 2 and higher mode. A new method for continuous sheared-flow generation is proposed for stabilization and heating of the FRCs by the use of intermittent merging of spheromaks with opposing toroidal field. We will present this concept by comparing our simulations with our TS-4 experiments. We simulated for the first time the FRC plasma with the intermittent merging of a pair of counterhelicity spheromaks using the MHD code. We will present how the intermittent merging maintains the flow shear as well as the stability of FRCs and then will show initial results in TS-4 intermittent merging experiment in comparison with the our simulation results.


## 1. Introduction

Recently, an interest has grown in generating field reversed configuration (FRCs) with large s (average number of ion gyroradii) for a future large scale confinement experiment. As the size and magnetic field of an FRC increase, its the s value tends to increase significantly, transforming the FRC stability from the small s kinetic regime into large s MHD regime. From an engineering point of view, a large-scale experiment also requires a slow formation of the FRC with high-energy efficiency, leading to several new formation technics in the MHD regime. We developed a slow formation method by which was two force force-free spheromaks with opposing troidal magnetic field were axially collided and were transformed into an oblate FRC [1]. And we also found this merging method generate sheared flow, leading to stabilization of n=1 (tilt and/or shift) modes [2].

## 2. Concept of Continuous Merging

Figure 1 shows a basic concept of continuous merging. Two merging force-free ($\beta$ = 5-10%) spheromaks are transformed into an oblate FRC with $\beta$ = 70-100%, generating sheared flow by $\mathbf{j}\times\mathbf{B}$ sling-shot effect. This sheared flow suppress the n=1 instability, so that the continuously merging

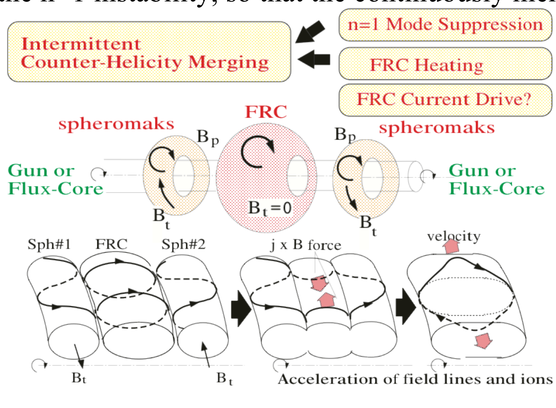


Fig.1. Continuous generation of sheared flow by multiple merging for stability / heating FRC.[]

of two counter-helicity spheromaks into oblate FRC leads to getting possibly improve the stability of steady-state FRC against n=1 mode.

This continuous merging technique is useful also for fuel-feeding and flux-injection not only in FRCs but also in spherical tokamaks (STs). The continuous merging ST scheme is almost the same as FRC.

Two small co-helicity ST formulated by coaxial gun or flux core merge a center main ST, supplying toroidal magnetic flux ($\psi_{tot} = \psi_{big} + 2\psi_{small}$) and particles to the main ST. It is difficult to provide toroidal plasma current (poloidal flux) by center solenoid coil because of narrow space in center stack of ST device. This continuous merging technique realizes new toroidal current drive of STs through q-value control by toroidal flux supplying.

### 3. MHD Simulation Model

We started modeling the continuous merging of FRCs by use of 2-D MHD simulation code [3]. It solves the resistive MHD equations using the explicit finite-difference method with forth-order accuracy both in space and time[3]. The initial condition of MHD simulation is obtained by solving the Grad-Shafranov equation and the two boundary between the main FRC and two spheromaks are connected with vacuum magnetic field.

### 4. First results of continuous merging experiment and simulation

Figure 2 shows the 2-D MHD simulation result of continuous spheromak merging with the main FRC. Both sides of spheromaks with counterhelicity merge together with center main FRC at 0 ~ 34 [$T_A$], generating toroidal sheared flow by the $\mathbf{j}\times\mathbf{B}$ force of the slingshot motion at 38 ~ 42 [$T_A$]. The sheared flow changes its polarity because it is generated by the repeating slingshot motion. This sheared flow is expected to saturate the n=1 instability and continuously repeating cycle of spheromak merging possibly fully suppress the low-n FRC's instability. Since the MHD equation does not include kinetic or two fluids effect, we are now arranging the particle code as the next step.

Figure 3 shows time evolution of poloidal flux contous when one small ST merges with the main ST after their merging formation side. First, two STs produced by both sides of flux core, merge together to form one main ST. Next, the 3rd ST collides into the produced main ST, supplying toroidal flux, plasma particles and generating sheared flow. These effects will be discussed in poster session in detail.

### 5. Summary

We numerically and experimentally demonstrated the continuous merging scheme useful for suppressing FRC's instability or supplying the magnetic flux to ST. We obtained the first numerical and experimental results for this scheme, and in our session, we will describe these two schemes in detail, and show initial results in TS-4 intermittent merging experiment in comparison with the simulation results.

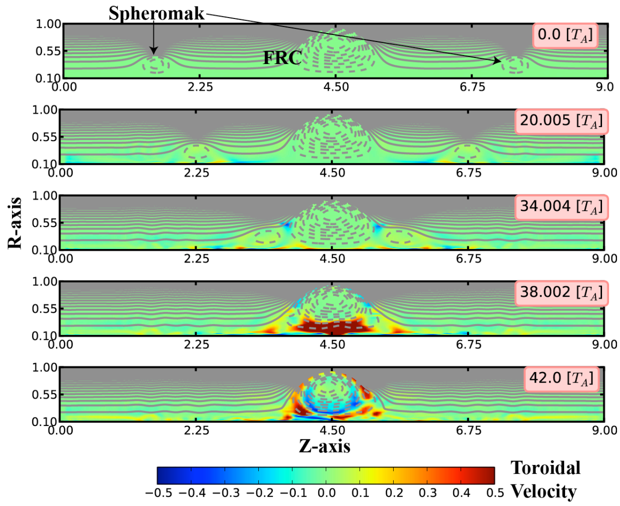


Fig.2 R-Z contours of poloidal flux and toroidal velocity (in color) when two small spheromak merge with the center main FRC (the MHD simulation).

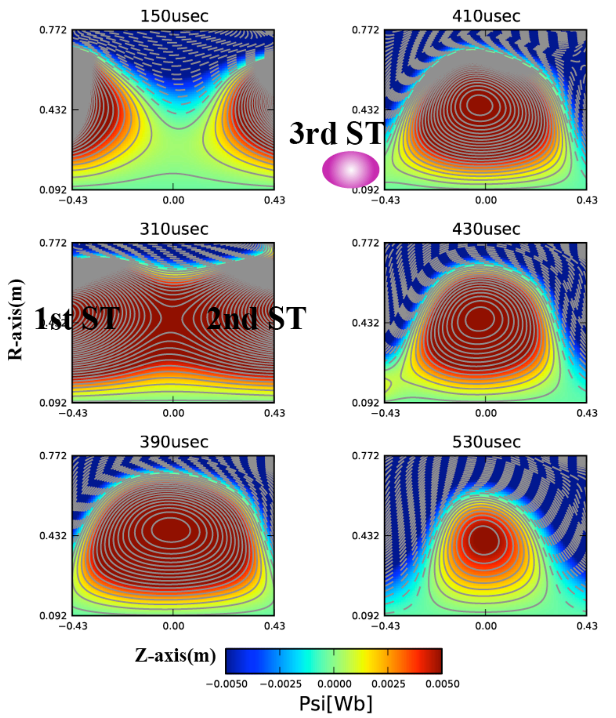


Fig. 3 R-Z poloidal flux contous when two ST merges together and the 3rd ST merge with the produced main ST.

### References


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