§15. MHD and Hybrid Simulations of High-beta Self-organized Plasmas to Emerge Two-fluid and/or Kinetic Effects

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Spherical torus (ST), reversed field pinch (RFP), and field-reversed configuration (FRC) plasmas are all high-beta torus plasmas and these exhibit active MHD nature. In the ST plasma, for example, the presence of flow, magnetic reconnection, and dynamo phenomena occur in the multi-pulsing helicity injection experiments, which relate with MHD relaxation and current drive. Besides, the spectrum of MHD fluctuations concentrates on a few toroidal modes in the RFP experiments, which results in forming a helical structure. Experimental results of FRC plasmas, on the other hand, show non-MHD nature for tilt mode stability; it implies that particle effects dominate FRC stability properties. Furthermore, the electromagnetic and velocity field structure of ST plasmas are well explained, based on the two-fluid relaxation theory. Therefore, MHD and non-MHD nature can probably coexist in high-beta self-organized plasmas. Here, in order to present two-fluid and kinetic effects seen in the self-organized plasmas and develop a more detailed physical model, we carry out both 3D non-linear MHD simulation and electron-fluid ion-particle hybrid simulation. In particular, we study the role of two-fluid and kinetic effects on a magnetic reconnection process, a flow and electric field formation, and magnetic fluctuations.

We have carried out the analysis of MHD as this fiscal year project. Firstly, we have carried out an axial collision process between two FRC plasmas[1]. As shown in Fig. 1, we reduce the axial mesh size in the reconnection region to 1/10 of that for the conventional calculation. Using the finer meshes, we calculate the MHD simulation, and obtained axial forces in the high spatial resolution region are presented in Fig. 2, where the 2D profile is plotted on the top and the 1D axial profile on the field-null surface is shown on the bottom. We found from the bottom figure that an attracting force is acting on the plasma core and a repulsive force however is acting on the colliding front surface. Therefore, this repulsive force inhibits a merging process. Resultantly, we never observed the complete merging that unifies the two field-null points. We are now developing a 3D hybrid simulation code and plan to complete until next fiscal year to compare the results from different calculation models.

Secondly, we have simulated ST translation and subsequent merging processes by the MIPS code developed in NIFS in order to study feasibility of novel fueling technique into plasma cores[2]. Although an active ballooning instability occurs during a translation process, we have observed successfully complete merging of two ST plasmas. As shown in Fig. 3, the secondary plasma is moving toward the main plasma, and a core merging process follows the magnetic reconnection.

1) Matsuzaki, K. *et al*.: PFR (2016) (in press).
2) Mitarai. O. *et al*.: Fusion Eng. Des. (2015). http://dx.doi.org/10.1016/j.fusengdes.2015.12.022

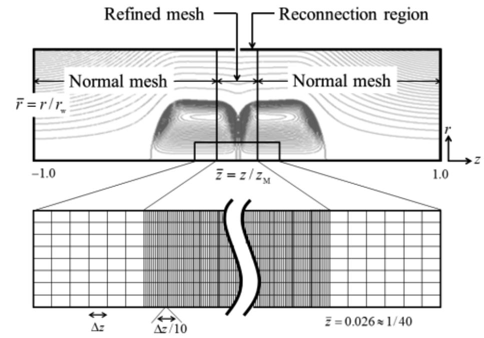

Fig. 1. (Top) Calculation region for two FRC collision process, (bottom) mesh refinement in the magnetic reconnection region.

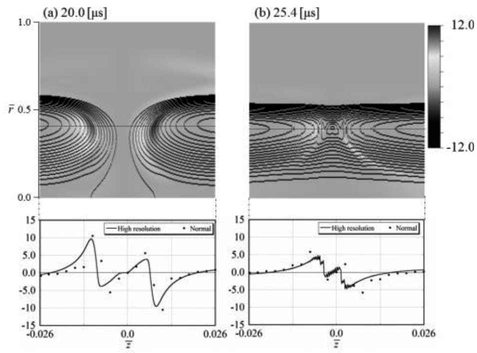

Fig. 2. (Top) 2D axial force profile in refined mesh region, (bottom) 1D axial force profile on a surface having the field-null points.

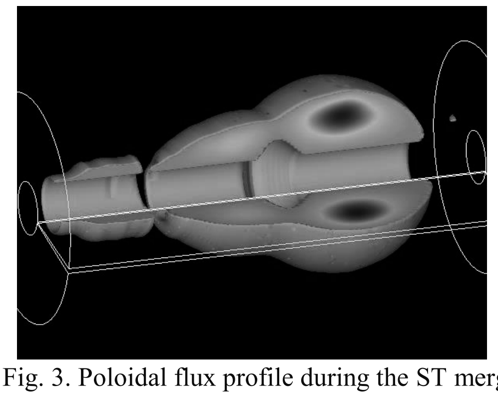

Fig. 3. Poloidal flux profile during the ST merging process.