§29. Nonlinear MHD Simulation of High-β Self-organized Plasmas

Kanki, T. (Japan Coast Guard Academy),
Sanpei, A. (Kyoto Inst. Tech.), Mizuguchi, N.

The HIST device at University of Hyogo forms the spherical torus (ST) plasmas, and the RELAX machine at Kyoto Institute of Technology does the reversed field pinch (RFP) plasmas. These plasmas have the common features of high-β and low-aspect-ratio self-organized magnetic configurations. On the HIST, the plasma flow, magnetic reconnection, and dynamo related to MHD relaxation/current drive are observed in the multi-pulsing coaxial helicity injection (M-CHI) experiment. On the RELAX, the spontaneous helical plasma structure that the magnetic fluctuations concentrate into a small number of modes is formed. In this way, these plasmas exhibit the complicated MHD behaviors due to the significant spatial changes of magnetic and flow structures and the high-β value. The purpose of this study is to comprehensively understand the nonlinear MHD behavior of the high-β and low-aspect-ratio self-organized plasmas by using a two-fluid equilibrium analysis and a resistive nonlinear 3D-MHD simulation.

For the ST equilibrium analysis, a two-fluid flowing equilibrium model which is described by a pair of generalized Grad-Shafranov equations for ion and electron surface variables and Bernoulli equations for density is applied to investigate the effects of M-CHI on the two-fluid equilibrium configurations, comparing with the experimental measurements. For the nonlinear MHD simulation, we solve a standard set of the nonlinear, resistive, and compressive MHD equations by using the MIPS code in a full-toroidal 3D geometry within the MHD time scale on the order of sub-millisecond. The initial conditions are given by a numerical equilibrium that follows the experimental conditions of RELAX. The equilibria are calculated by the Grad-Shafranov solver with a fitting reconstruction, the RELAXFit code.

For the ST equilibrium analyses, it has been revealed that the toroidal magnetic field becomes from a diamagnetic to a paramagnetic profile in the closed flux region as the negative density gradient caused by the M-CHI becomes steeper in the central open flux column (OFC) region[1),2)]. The poloidal ion flow velocity is increased in the direction of the current around the separatrix in the high field side as shown in Fig. 1, because the ion diamagnetic drift velocity is changed in the same direction as the $\boldsymbol{E} \times \boldsymbol{B}$ drift velocity through the steeper negative ion pressure gradient. The poliodal flow shear is enhanced in the closed flux region. The toroidal ion flow velocity is increased from negative to positive values in the closed flux region as shown in Fig. 2, enhancing the paramagnetic poloidal field. Here, the negative ion flow velocity is the opposite direction to the current. Both the poloidal and toroidal ion flow velocities tend to contribute the increase of plasma currents. The M-CHI effects lead the increase of plasma currents and magnetic flux.

The 3D-MHD simulation results for the RFP successfully reproduced the basic nature of the experimentally observed helical structures in the RELAX with the n=4-5 components[3)]. Such helical structures can be formed from the initial conditions both with and without a resonant rational surface. In addition, the simulation results imply that there can be a unique helical relaxed state in the RFP with a bean-shaped hollow pressure profile in the poloidal cross section as shown in Fig. 3.

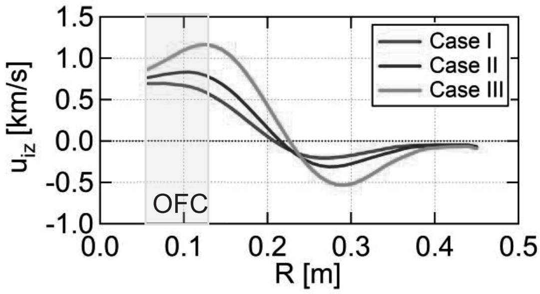

Fig. 1: Radial profiles of the poloidal ion flow velocity u_{iz} at the midplane.

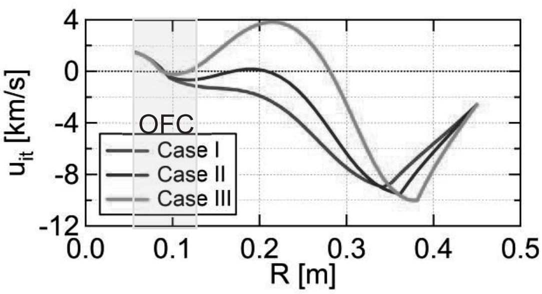

Fig. 2: Radial profiles of the toroidal ion flow velocity u_{it} at the midplane.

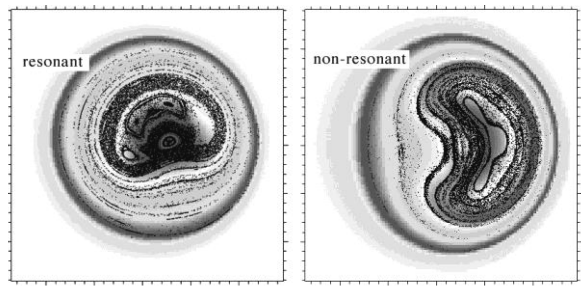

Fig. 3: The relaxed helical structure in the RFP with a bean-shaped hollow profile in the poloidal cross section.

1) Kanki, T. and Nagata, M. : 17th ICPP, Lisbon, Portugal, 15-19 Sep. 2014, MCF.P7.
2) Kanki, T. and Nagata, M. : 56th APS-DPP Meeting, New Orleans, USA, 27-31 Oct. 2014, BP8.0007.
3) Sanpei, A., Mizuguchi, N., Masamune, S. et al. : US-J JIFT Workshop, Kyoto, Japan, June 5-6, 2014.