§8. MHD Relaxation in High-β Toroidal Plasmas

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Energy relaxation phenomena have been observed in high-β torus plasmas such as super-dense-core state in the LHD, RFP, spheromak and spherical tokamak (ST). Comprehensive understanding of the relaxation mechanism is of fundamental importance for high-β torus plasmas. In this study, we address our attention to MHD relaxation phenomena in ST during coaxial helicity injection (CHI). The CHI with a magnetized coaxial plasma gun (MCPG) is an attractive sustainment method which has been used as non-inductive current drive and plasma startup in spheromak and ST. However, a critical issue of the CHI is the evidence that during the relaxation, the central open flux column (COFC) around the central post develops a helical distortion due to the nonlinear growth of the n=1 kink instability and the magnetic reconnection destroys the closed flux. In order to improve this defect of the CHI, the multi-pulsed operation of CHI (M-CHI) that causes a stepwise buildup of the magnetic field of the configuration by pulsing a MCPG has been proposed to achieve quasi-steady state plasma with increase of the current flowing in closed flux region. The M-CHI has been for the first time demonstrated in the SSPX gun-spheromak device[1] and performed in the HIST spherical torus device[2] to obtain both improved energy confinement and sustainment. The purpose of this study is to investigate the mechanism to rebuild the magnetic fields by using resistive nonlinear 3D-MHD simulations[3]. We focus our attention on the effects of the M-CHI on dynamics of the low-q ST (q<1).

We use a 3D full-toroidal cylindrical (r, θ, z) geometry, and divide the simulation region into two cylinders with a central conductor inserted along the symmetry axis. One is a gun region corresponding to the MCPG region, and the other is a confinement region. The insertion of a toroidal field current I_{tf} along the geometry axis inside the central conductor produces a vacuum toroidal field, creating a tokamak configuration. We set I_{tf}= 0.2 because of considering a low-q ST. The governing equations to be solved in the simulation are the set of nonlinear resistive MHD equations. To solve the equations, we use the second-order finite differences method for the spatial derivatives and the fourth-order Runge-Kutta-Gill method for the time integration. A bias magnetic flux penetrates electrodes at the inner and outer boundaries of the gun region to drive the plasma current by applying an electric field in a shape of pulse. We use a perfect conducting boundary at the wall of the confinement region. The initial conditions for the simulation are given by an axisymmetric MHD equilibrium, which can be obtained by numerically solving a Grad-Shafranov equation under these boundary conditions. In the simulation, the mass density is spatially and temporally constant and no-slip wall condition is assumed at all boundaries of the simulation region. We also impose that the heat flux can pass through all the boundaries.

The simulation result shows the time evolution of magnetic fields on the poloidal cross section (see Fig. 1). During the driven phase, the ST has helical distortion of the COFC, because the n=1 kink mode of the COFC is destabilized beyond the Kruskal-Shafranov limit. The poloidal flux amplification occurs due to the merging of the pre-existing plasma with the ejected one which involves magnetic reconnections. During the decay phase, the ST approaches the axisymmetric MHD equilibrium state without flow due to the dissipation of magnetic fluctuations to increase the closed flux surfaces. At t=298τ_A, the helical distortion of the COFC vanishes and then ordered magnetic field structures are formed. Comparative analysis with the HIST experimental results is our ongoing study.

1) Woodruff, S. *et al.*, Phys. Rev. Lett. **93**, (2004) 205002.
2) Nagata, M. *et al.*, *Proc. 23rd IAEA Fusion Energy Conference* (Daejon, Korea, 10-16 Oct. 2010) EXC/P2-04.
3) Kanki, T. *et al.*, Plasma and Fusion Res. **5**, (2010) S2055.

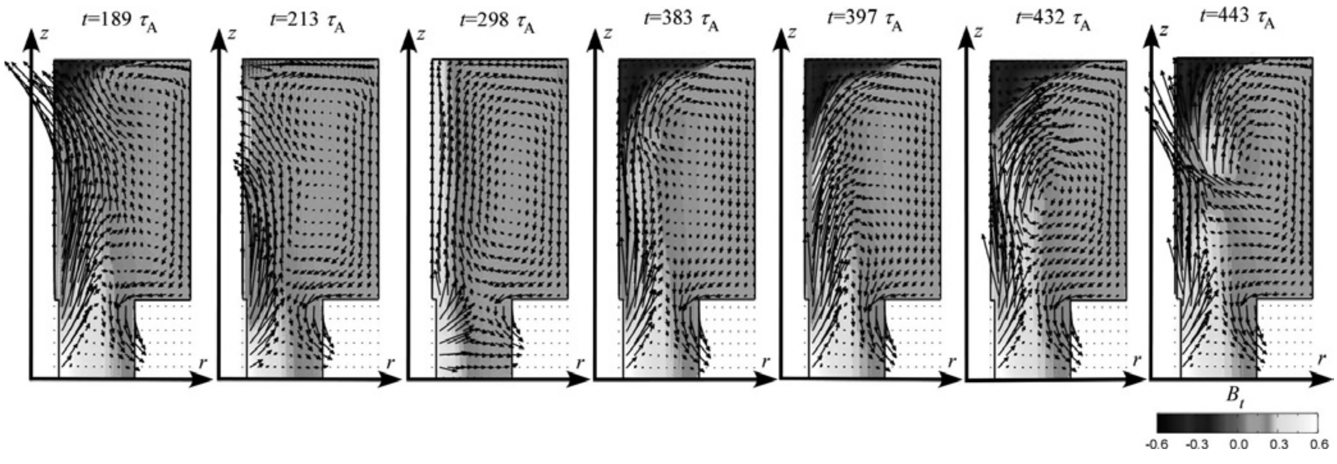

Fig. 1. Time evolution of vector plots of poloidal field B_p and contours of toroidal field B_t on the poloidal cross section.