§19. Nonlinear MHD Behavior of High-β Low-aspect-ratio Tori

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Magnetic configurations formed in the spherical torus (ST) machine, HIST at University of Hyogo and the low-aspect-ratio reversed field pinch (RFP) machine, RELAX at Kyoto Institute of Technology are characterized by high-β self-organized plasmas. Significant spatial variations of magnetic and flow structures related to the nonlinear MHD behavior have been observed in the formation of spontaneous helical structure on the RELAX and the multi-pulsed coaxial helicity injection (M-CHI) operation on the HIST. Comprehensive understanding of the nonlinear MHD behavior is of fundamental importance for the high-β low-aspect-ratio tori. The purpose of this study is to investigate the nonlinear MHD behavior of ST during the M-CHI by using resistive nonlinear 3D-MHD simulations.

We use a 3D full-toroidal cylindrical geometry (r, θ, z), and divide the simulation region into gun and confinement regions. The insertion of a toroidal field current $I_{\rm tf}$ along the geometry axis produces a vacuum toroidal field, creating a high-q ST (q>2). To solve the set of nonlinear resistive MHD equations, we use the second-order finite differences method for the spatial derivatives and the fourth-order Runge-Kutta method for the time integration. A bias flux penetrates electrodes of the gun region to drive the plasma current by applying an electric field $E_{\rm inj}$ in a shape of pulse. We use a perfect conducting boundary at the wall of the confinement region. The initial conditions 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 except for the gap between electrodes. The $\boldsymbol{E}\times\boldsymbol{B}$ drift velocity is given at the gap. We also impose that the heat flux can pass through all the boundaries.

The simulation results show the time evolution of velocity fields on the poloidal cross section (see Fig. 1). During the driven phase, the strong poloidal flow $v_{\rm p}$ (=$E_{\rm r}B_{\rm t}$) moves from the gun to confinement region due to the Lorentz force. From t=926$\tau_{\rm A}$ to t=970$\tau_{\rm A}$, the negative toroidal flow $v_{\rm t}$ which is the same direction as the toroidal current is driven around the central open flux column (OFC) region by inductive toroidal electric field $E_{\rm t}$ (=-$v_{\rm p}B_{\rm r}$) because of the plasmoid ejection. After that, the positive $v_{\rm t}$ associated with the dynamo effect is generated around the OFC region. During the decay phase (t=1167$\tau_{\rm A}$), both $v_{\rm t}$ and $v_{\rm p}$ decay, and then the configuration approaches a static MHD equilibrium of ST due to the dissipation of magnetic fluctuations to rebuild the closed field lines. Just after turning off the $E_{\rm inj}$ (t=1101$\tau_{\rm A}$), the $v_{\rm p}$ which moves from the confinement to gun region is caused by the pressure gradients. The vortices of $v_{\rm p}$ then expands all over not only confinement region but also gun region. Comparative analysis with the HIST experimental results is our ongoing study.

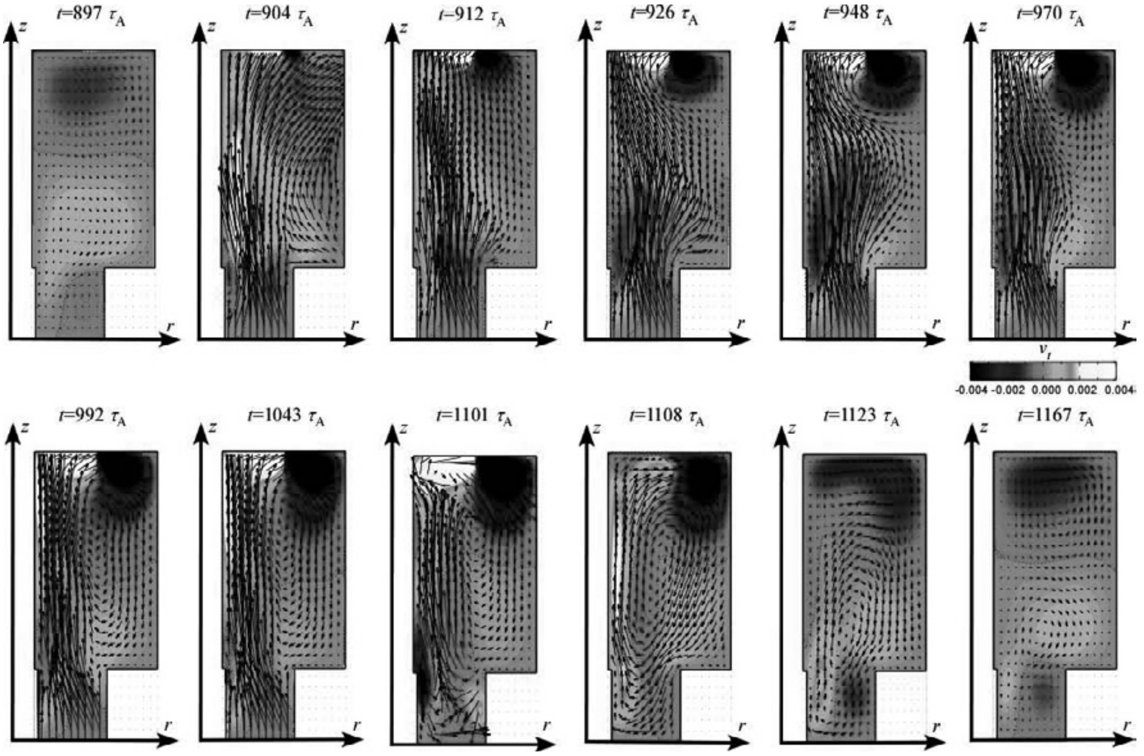

Fig. 1. Time evolution of vector plots of poloidal flow velocity $v_{\rm p}$ and contours of toroidal flow velocity $v_{\rm t}$ on the poloidal cross section at the θ=0 plane.