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MHD Simulation of Multi-pulsed Current Drive by Coaxial Helicity Injection in Spherical Torus

同軸ヘリシティ入射による球状トーラスのマルチパルス電流駆動のMHDシミュレーション

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A 3-D MHD simulation of a multi-pulsed current drive by coaxial helicity injection on a spherical torus (ST) plasma is carried out for the high safety factor q range (q>2) of a corresponding experiment conducted on the HIST device. The simulation results show that during the driven phase, the poloidal flux and the toroidal current are amplified by the axisymmetric merging of the pre-existing ST plasma with ejected one which involves magnetic reconnection. Of particular interest is observed during the decay phase that the ST approaches the axisymmetric MHD equilibrium state without flow due to the dissipation of magnetic fluctuations to rebuild the closed flux surfaces.

1. Introduction

Coaxial helicity injection (CHI) which has been used as non-inductive current drive and plasma startup by a magnetized coaxial plasma gun (MCPG) is one of the more attractive methods in spheromak and spherical torus (ST) because of its possibility of high efficiency. However, a critical issue of the CHI is the evidence that during the sustainment, the central open flux column (COFC) develops a helical distortion due to the nonlinear growth of the n=1 kink instability and the subsequent magnetic reconnection destroys the closed flux surfaces. In order to improve this demerit 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 with increase of the current flowing in closed flux surfaces region. The M-CHI has been for the first time demonstrated in the SSPX device [1] and performed in the HIST device [2] to obtain both improved energy confinement and sustainment. The purpose of present study is to investigate the effects of the M-CHI on dynamics of the high-q ST by using resistive nonlinear 3D-MHD simulation [3].

2. Simulation Model

We use a 3D full-toroidal cylindrical (r, θ, z) geometry. The simulation domain consists of a gun region and 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. The governing equations 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 method for the time integration. A bias magnetic flux penetrates electrodes at the inner and outer boundaries of the gun region, and an electric field is applied to the gap between electrodes in the shape of periodic pulses. We use a perfect conducting boundary at the wall of the confinement region. The initial conditions are given by an axisymmetric MHD equilibrium of high-q ST with finite pressure gradients, 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. We also impose that the heat flux can pass through all the boundaries.

3. Simulation Results

As shown in Fig.1, during the driven phase from t=600 to 800τ_A, the poloidal flux and the toroidal current are amplified by the axisymmetric merging of the pre-existing ST plasma with ejected one which involves magnetic reconnection, because the n=0 mode is dominant to other modes. As shown in

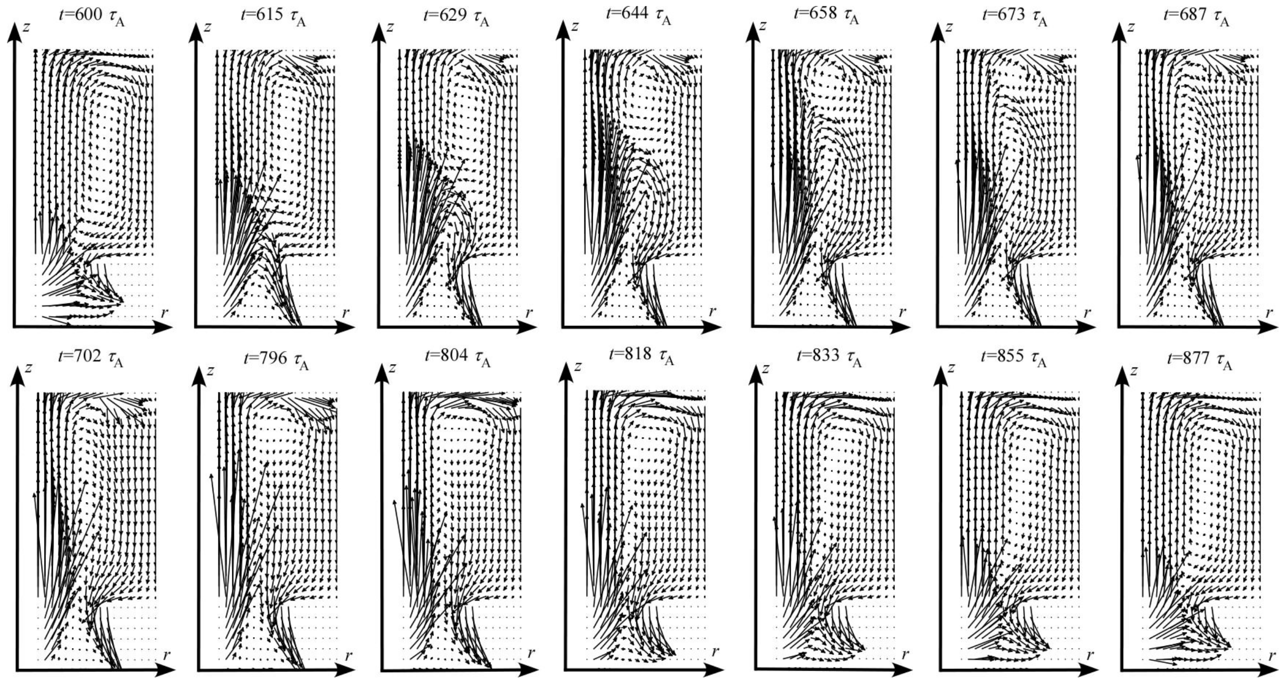

Fig.1. Time evolution of vector plots of poloidal field B_p on the poloidal cross section at the θ=0 plane.

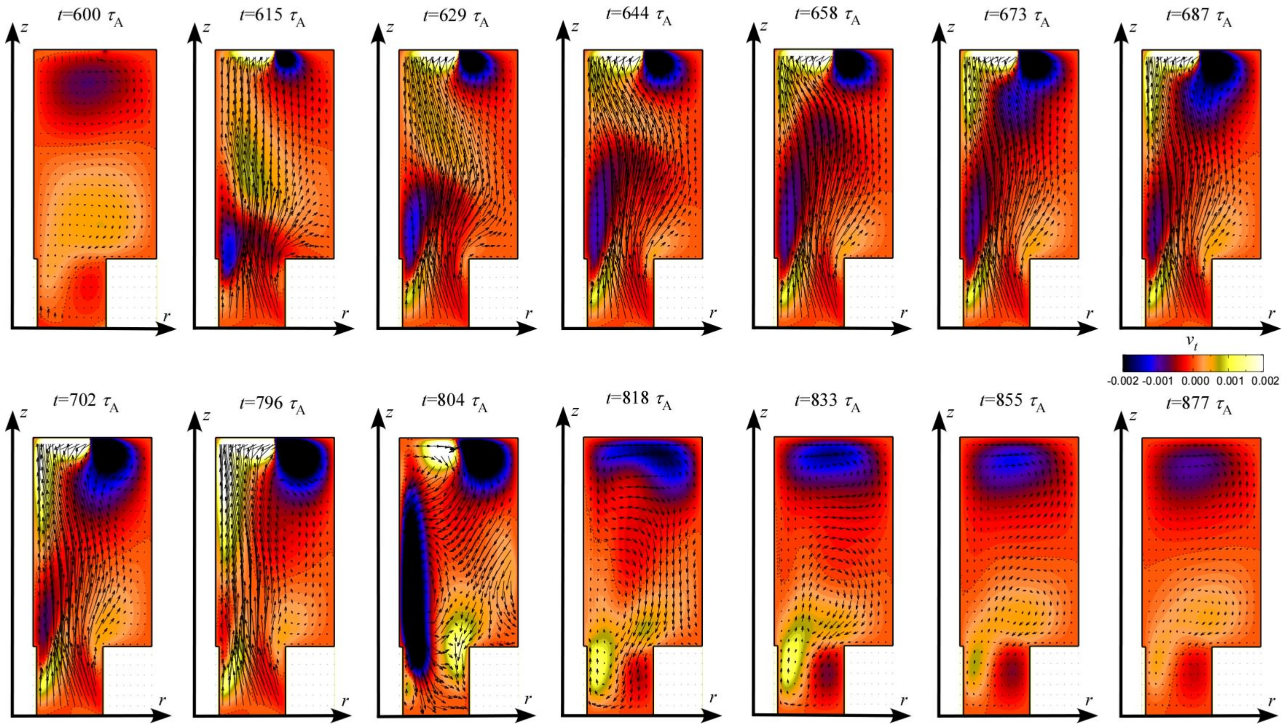

Fig.2. Time evolution of vector plots of poloidal flow velocity v_p and contours of toroidal flow velocity v_t on the poloidal cross section at the θ=0 plane.

Fig.2, in this merging process, due to the Lorentz force, the strong poloidal flow which moves from the gun to confinement region occurs, and the toroidal flow is driven in the same direction as the toroidal current in the COFC region. During the decay phase from t=800 to 900τ_A, the ST approaches the axisymmetric MHD equilibrium state without flow due to the dissipation of magnetic fluctuations to rebuild the closed flux surfaces. At t=804τ_A, the poloidal flow which moves from the confinement to gun region is induced due to the pressure gradients.

References

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