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Nonlinear MHD simulation on the formation of helical structure in RFP
逆磁場ピンチにおける３次元構造の形成に関する非線形ＭＨＤシミュレーション

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Nonlinear three-dimensional magnetohydrodynamic(MHD) simulations have been applied to the reversed-field pinch(RFP) plasma to reveal the physical mechanism of the formation processes of helical structures, such as so-called the quasi-single helicity (QSH) state. The simulations are executed by using the MIPS code in a realistic experimental geometry of the RELAX device with reconstructed initial equilibria calculated by the RELAXFit code. Long term evolutions have shown remarkable formation of n=4 structures as a result of dominant growth of the m/n=1/4 resistive mode. The quasi relaxed helical state consists of a bean-shaped and hollow pressure profile in the poloidal cross section. The simulation results are compared with the experimental observations in RELAX.

1. Introduction

The reversed-field pinch (RFP) is an elaborate toroidal confinement concept, in which the plasma is sustained by making use of its formative nature with a simple and compact magnetic system. The configurations can contain high-beta plasma with intrinsic large toroidal current, which simultaneously provides effective Ohmic heating for a potential reactor. On the other hand, the system tends to be destabilized for the tearing mode instabilities in the core region because of the large current and the adjacent rational magnetic surfaces. The existence of such multiple rational surfaces can cause interactions between the modes and chaotizing of the field lines. To avoid such a way of degradation of confinement, a passive control method is examined experimentally. Namely, by concentrating most of the mode activity into a single mode, a large magnetic island, in which the confinement property is improved, is formed in the core region. Several types of such a small number of helicity state have been observed experimentally[1,2], i. e., the quasi single helicity (QSH), in which almost all activities converge into a single mode, or the single helical axis (SHAx) state, in which the secondary arising zero point forms another three-dimensional magnetic axis. In the REversed field pinch of Law-Aspect ratio eXperiment "RELAX", the rotation of the helical structure are observed[2].

In this study, we apply the nonlinear three-dimensional magnetohydrodynamic (MHD) simulation which has been developed for more than ten years at the National Institute for Fusion Science (NIFS) for modeling of the tokamak or helical plasmas[3] to the RFP system. The simulation results are immediately compared with the experimental data of RELAX. By collaborating the numerical simulation with the experiment, we aim at revealing the unknown dynamics on the formation of helical structures in RFP.

2. Simulation Model

We solve the standard set of the nonlinear, resistive, compressive MHD equations explicitly with the 4th-order finite difference and Runge-Kutta scheme by using the MHD Infrastructure for Plasma Simulation (MIPS) code [4]. The numerical grid is a cylindrical full-toroidal geometry with a rectangular mesh in the poloidal plane. The grid size is (112,112) for the poloidal plane, and 128 for toroidal direction. The initial condition is reconstructed experimental equilibria obtained by the RELAXFit code[5].

As a nature of RFP, the toroidal magnetic field passes through zero near the peripheral region. In other words, the safety factor, q, goes to zero which allows all the toroidal modes to be destabilized for the m=0 mode, where m is the poloidal mode number. By setting the adhering conductor wall in the plasma boundary, such m=0 modes can be effectively suppressed.

3. Simulation Result

Perturbations applied in the initial equilibrium can spontaneously grow with the dominant n=4 mode, where n indicates the toroidal mode number. The growth rate strongly depends on the resistivity. The poloidal component is almost single m=1 mode. Although the initial equilibrium contains slightly the q=1/4 surface in the central region, the displacement of the growing m/n=1/4 mode extends globally, as shown in Fig.1(a). Figure 2 shows the time development of the total kinetic energy. As shown here, the system experiences two peaks of energy and quasi relaxed state at t=305τ_A, where τ_A is the Alfven transit time.

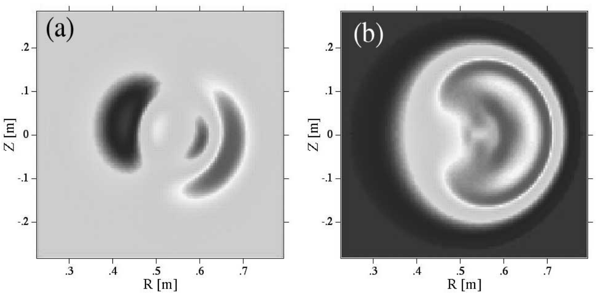

Fig.1. (a)Fluctuation component for the n=4 mode. (b)Poloidal pressure profile at t=305τ_A.

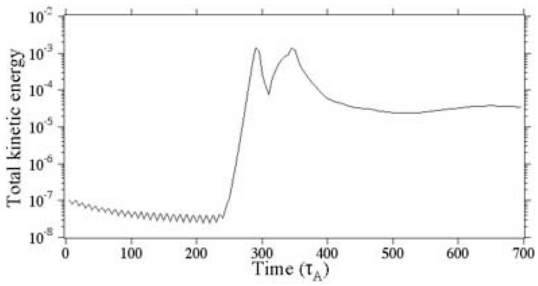

Fig.2. Time development of total kinetic energy

At t=305τ_A, the system ceases by keeping the n=4 deformation, as shown in Fig. 3. The plasma flows concerning the helical deformation and the poloidal equilibration along the magnetic surfaces make the shape of the plasma poloidal cross section into a bean shape. Moreover, the poloidal flows formed mainly in the off-axis region causes the poloidal profile hollow, as shown in Fig.1(b).

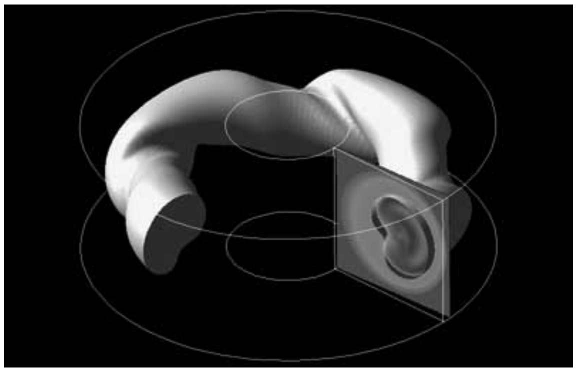

Fig.3. Formation of helical structure in RFP obtained by the nonlinear MHD simulation. A contour map and an iso-pressure surface is plotted.

After t=305τ_A, the system are rapidly rearranged, maybe because of some magnetic reconnections in the core region. The system becomes highly disordered state with multiple mode number components.

4. Summary

Nonlinear MHD simulations have reproduced the formation of quasi relaxed helical structure in RFP. The results are comparable to the observations in RELAX. It is found that non-resonant resistive instability forms a bean-shaped hollow profiles with an n=4 deformation.

Acknowledgments

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