§23. Modeling of Helical-Structure Formation in Reversed-Field Pinch

Sanpei, A., Masamune, S., Oki, K., Himura, H. (Kyoto Inst. Tech.),
Mizuguchi, N., Ichiguchi, K.

Nonlinear three-dimensional MHD simulations have been executed for the low-aspect-ratio reversed-field-pinch(RFP) plasma to reveal the physical mechanism of the formation processes of helical structures[1]. The simulation results show a clear formation of $n = 4$ structure as a result of dominant growth of resistive modes. The resultant relaxed helical state consists of a unique bean-shaped and hollow pressure profile in the poloidal cross section both for the cases of resonant and non-resonant triggering instability modes. The results are partially comparable to the experimental observations.

To avoid the degradation of confinement due to the chaotizing of the field lines in the core region of RFP, a unique control method making use of the self-concentrating nature of the plasma perturbations into a small number of modes has been proposed both experimentally and theoretically. Several types of such states have been observed, such as the quasi-single helicity (QSH) and the single helical axis (SHAx) states. However, the physical mechanisms for the formation and deformation of the structures have not been clarified well.

In this study, we apply the nonlinear 3-D MHD simulations which have been well established for modeling the tokamak or helical plasmas to the RFP system. Time development of plasma is calculated by using the MIPS code. A standard set of the nonlinear resistive compressive MHD equations is solved explicitly in a cylindrical full-toroidal geometry with finite difference grids. The initial conditions are the reconstructed equilibria which roughly follow the RELAX data obtained by the RELAXFit code. Two cases, where the $q = 1/4$ rational surface does(Case D) and does not(Case C) exist, are examined.

Under the condition of finite resistivity, the $n = 4$ component dominates the growth compared to the other modes for both cases. The system undergoes relaxations twice before the dissipative phase of long duration. Such a transient concentration to the $n = 4$ mode is also observed in the experiment. It should be noted that the dominant component is the $n = 4$ mode for both cases.

The corresponding changes in the poloidal cross section are shown in Fig.1. The poloidal contour gradually deforms into a bean-shaped structure for both of the cases, reflecting the linear eigenmode structure with the $m = 1$ component. At the relaxed states (Fig.1(c) and (f)), each of the poloidal pressure profiles reaches to a highly hollow and deformed ring structure with a large hole. Such a hollow bean-shaped helical structure appears for a wide range of parameters and profiles in the simulation.

The formation mechanism of the hollow structure is different between the two cases. For Case D, the resonant $m/n = 1/4$ mode grows with a large single magnetic island (Fig.1(b)), showing a typical behavior of the tearing modes. The original magnetic axis shrinks gradually, whereas the created O-point of the island forms a new magnetic axis. Such a mechanism has been conventionally proposed for the model of the QSH or SHAx states. On the other hand, for Case D, a similar helical structure is still formed in the relaxation process. In this case, the original nested surfaces are directly deformed into a helical one by the non-resonant mode (Fig.1(e)). Then, for both of the cases, the core pressure flows out along the deformed magnetic field lines, probably through a magnetic reconnection between the core and the bean-shaped surface region. The resultant pressure profile forms a bean-shaped bank. The investigation of the physical properties of the relaxed state and detailed comparison with the experiments are our ongoing research.

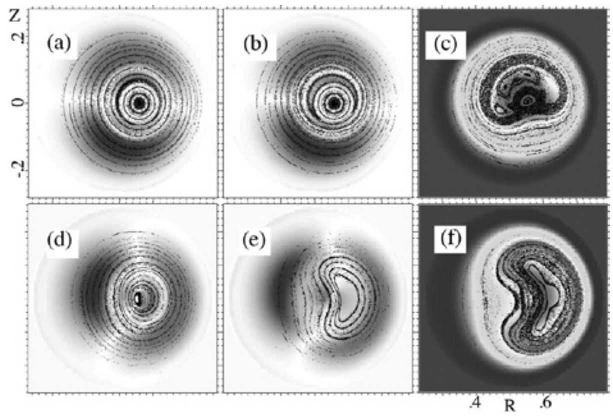

Fig. 1: Time development of the magnetic configuration. Puncture plots of the magnetic field at (a)t=240, (b)250, (c)260τ_A for Case D, and (d)280, (e)290, (f)300τ_A for Case C are shown on the color contour of the n=4 component((a),(b),(d), and (e)) and the net((c) and (f)) pressure.

1) N. Mizuguchi, *et al.*, "Modeling of Formation of Helical Structure in Reversed-Field Pinch", Plasma Fusion Res., (2012), in press.