§18. MHD Dynamics of High-beta RFP Plasma on Structure Formations

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Comparative analyses between the nonlinear three-dimensional MHD simulation results[1)] and the experimental observation at RELAX device[2)] have been carried out for the low-aspect-ratio reversed-field-pinch(RFP) plasma to reveal the physical mechanism of the formation processes of helical structures. The simulation results show a clear formation of n=4 structure as a result of dominant growth of resistive modes, where n represents the toroidal mode number. The resultant relaxed helical state consists of a unique bean-shaped and hollow pressure profile in the poloidal cross section for both cases of resonant and non-resonant triggering instability modes.

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.

We solve a standard set of the nonlinear, resistive, and compressive MHD equations by the MIPS code in a full-toroidal three-dimensional geometry to investigate the dynamical behavior of RFP plasma on the structural changes within the MHD time scale on the order of sub-millisecond. The initial conditions for the simulation are given by a numerical equilibrium that roughly follows the experimental conditions of RELAX. The equilibria are calculated by the Grad-Shafranov solver with a fitting reconstruction, the RELAXFit code. Two typical cases, where the $q = 1/4$ rational surface does and does not exist, are examined.

The simulation results show the dominant growth of the n=4 mode for both cases with and without the $q = 1/4$ surface. For the resonant case, the $m/n = 1/4$ mode grows with a large single magnetic island, 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. In the nonlinear stage, the system experiences a relaxed state with helically twisted shape. The poloidal cross section deforms into a bean shape with a highly hollow pressure profile. Such a hollow profile are found to be formed through a magnetic reconnection process which is induced near the core region due to the plasma flows of the instability modes.

Comparing with the experimental observations, we may acknowledge the validity of the simulation. The helical deformation of SXR emissivity predicted by the simulation described in upper panel of Fig. 1 can explain an experimental result of successive SXR imaging diagnostic from vertical port shown in middle panel.

Left lower panel shows poincare map obtained in relaxed state of the simulation. As mentioned above, we can observe a large magnetic island due to m=1 internally resonant tearing mode. Right lower panel shows experimental SXR emissivity distribution on poloidal cross section calculated from vertical SXR images with computed tomography technique. Both of these m=1 deformations are corresponding to $m/n = 1/4$ helical deformation.

This comparative analyses would deepen our understanding of the self-organizing phenomena in a low-aspect and high-beta fusion plasma. To find out the basic constraint of the relaxation and its application to the experimental improvement is the next step of our research.

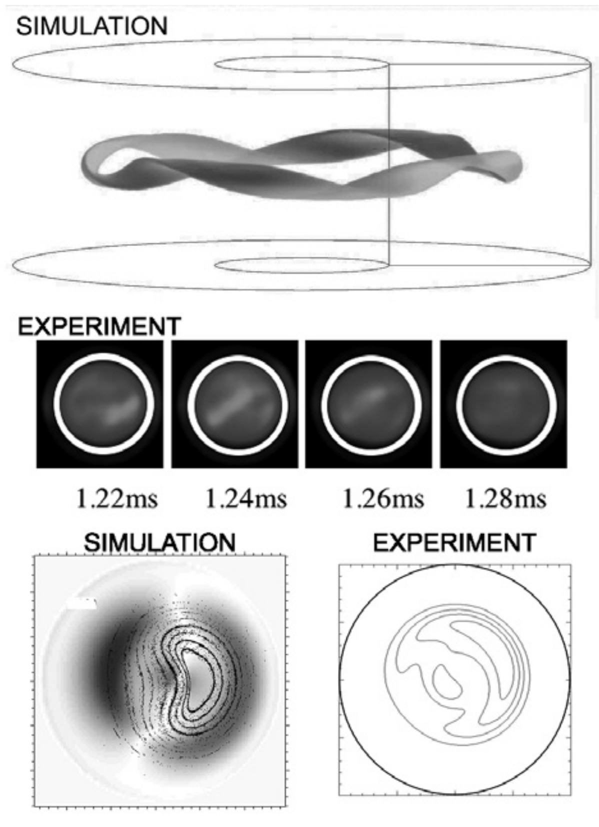

Fig. 1: Simulation and experimental results of the helical structures in RFP plasma. A hellically twisted overall structure (upper panels) and a bean-shaped deformation or a magnetic island structure (lower panels) are shown.

1) N. Mizuguchi, A. Sanpei, et al. : 24th IAEA-FEC, San Diego (2012), TH/P3-26.

2) A. Sanpei, et al. : IEEE Transaction Plasma Science, **39**, 2410 (2011).