§31. Theoretical Study about a Role of MHD Dynamics on Self-organization in a High-beta Toroidal Plasma

Sanpei, A. (Kyoto Inst. Tech.), Takahashi, T. (Gunma Univ.), Mizuguchi, N.

Comparative analyses between the nonlinear three-dimensional MHD simulation results[1, 2] and the experimental observation at RELAX device[3, 4] 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. Moreover, comparison our simulation results with its of NIMROD code in order to validate.

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. The simulation results successfully reproduced the basic nature of the experimentally observed helical structures in RELAX with the n=4-5 components. In addition, the simulation results imply that there can be a unique helical relaxed state in an RFP with a bean-shaped hollow pressure profile in the poloidal cross section.

Moreover, we make a comparison between our MIPS result and NIMROD result in association with Dr. Karsetn McCollam, University of Wisconsin. Using the NIMROD code, we simulate the nonlinear evolution of plasmas similar to those in the RELAX RFP experiment, whose relatively modest Lundquist numbers around the 10^4 range are tractable given our present computing resources. Machine diagnostics that can be used for validation purposes are Thomson scattering for electron temperature, interferometry for electron density, SXR imaging, and external and internal magnetic probes. RELAX's small aspect ratio (≈ 2) motivates a comparison study using toroidal and cylindrical geometries in NIMROD. Establishing cases for RELAX comparisons with NIMROD scan of paramagnetic pinch initial conditions have shown that as initial on-axis $\lambda \propto J_{\|}/B$ is increased, resulting reversal becomes deeper. From NIMROD code, we observed n= 4-6 mode become dominant at the case starting from same initial distribution as MIPS used. These simulations are comparable and still in the process of entering nonlinear states appropriate for comparisons to experiment.

Merging phenomena of two FRC plasmas and those of two ST plasmas have been calculated by an MHD model in Gunma University[5]. The MIPS code is used for ST merging processes in order to study feasibility of a nobel fuelling technique into the ST core region of an advanced fuel fusion reactor. In our scenario, a secondary compact ST plasma is translated by a sequential external field control and is injected into the main ST through a magnetic reconnection process. Our simulation results have shown that a balooning instability is observed before merging and resultantly the peak value of plasma pressure of the main ST decreases abruptly. We have, however, observed a ST merging process successfully. Future studies will be devoted to the analysis of fuelling feasibility when stable ST plasmas are considered.

These 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.

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2) S. Masamune, *et al.*, : 25th IAEA Fusion Energy Conf., (2014) EX/P3-52.

3) A. Sanpei, *et al.* : JPS Conf. Proc., **1**, (2014) 015027.

4) K. Nishimura, *et al.* : Rev. Sci. Inst., **85**, (2014) 033502.

5) K. Matsuzaki, *et al.* : IEEJ Transactions A, **135**, (2015) 296.