§3. Nonlinear Magnetohydrodynamics on Structural Changes in RFP and ST

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Scope   The reversed field pinch (RFP) plasma formed in the RELAX machine at Kyoto Institute of Technology and the spherical tokamak (ST) plasma in the HIST device at University of Hyogo are both characterized by high-β and low aspect ratio, self-organized configurations. There are common evidences of significant spatial changes in those plasmas. In 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, to avoid the degradation of confinement due to the chaotizing of the field lines in the core region of RFP. Several types of those helical states have been observed, such as the quasi-single helicity (QSH) and the single helical axis (SHAx) states. On the other hand, variations of magnetic and flow structures have been observed in the multi-pulsed coaxial helicity injection (M-CHI) operation on the HIST. Comprehensive understanding of the nonlinear MHD behavior for the high-β low-aspect-ratio tori, by using a nonlinear 3D MHD simulation and a two-fluid equilibrium analysis, is the purpose of this study.

Model   For the nonlinear simulation, we solve a standard set of the nonlinear, resistive, and compressive MHD equations by using the MIPS code in a full-toroidal 3D geometry within the MHD time scale on the order of sub-millisecond. The initial conditions are given by a numerical equilibrium that follows the experimental conditions of RELAX. The equilibria are calculated by the Grad-Shafranov solver with a fitting reconstruction, the RELAXFit code. For the ST equilibrium study, a two-fluid flowing equilibrium model which is described by a pair of generalized Grad-Shafranov equations for ion and electron surface variables and Bernoulli equations for density[1] is applied to investigate the properties of the magnetic field and plasma flow structures, comparing with the experimental measurements.

Results   In addition to our previous RFP simulations, which reproduce the appearance of helical structures with competitive developments of both internal resonant and non-resonant modes, like the experimental observations[2][3], we have examined another case with a deeply reversed initial configuration to investigate the contribution of the tearing-mode instabilities. The simulation result shows a relaxing to a helical structure with the $m/n = 1/5$ component (Fig.1). The pressure profile

again shows a highly hollow one. Linear stability analyses should be applied to clarify the causality of triggering modes for future plan.

For the ST analyses[4], it has been revealed that the toroidal field has a diamagnetic profile in the central open flux column (OFC) region due to the negative steep density gradient in high field side. The ion flow velocity with strong flow shear from the separatrix in the inboard side to the core region is the opposite direction to the electron flow velocity due to the diamagnetic drift through the density gradient (Fig.2). The electric field is relatively small in the whole region, and thus the Lorentz force nearly balances with the two-fluid effect which is particularly significant in a region with the steep density gradient due to the ion and electron diamagnetic drifts.

More detailed and systematic analyses and a comparative study between RFPs and STs are our ongoing subjects.
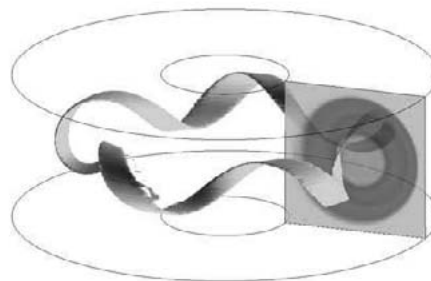

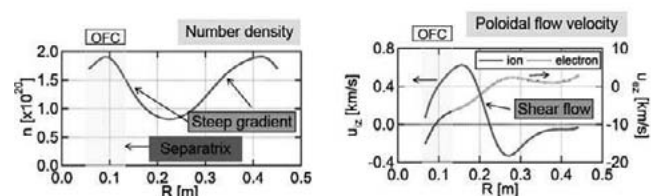Fig. 1: A relaxed helical structure for the tearing-mode evolution in the RFP.

Fig. 2: Density (left) and poloidal flow (right) profiles of the two-fluid equilibrium for the ST.

1) T. Kanki and M. Nagata : 40th EPS Conf. Plasma Phys., Espoo, Finland, 1-5 July 2013, P2.137.

2) S. Masamune, A. Sanpei, N. Mizuguchi et al. : APPC12, Chiba, July 14-19, 2013, D1-1-O3.

3) A. Sanpei, N. Mizuguchi, S. Masamune : US-J JIFT Workshop, Denver USA, Nov. 9-10, 2013.

4) T. Kanki and M. Nagata : 55th APS-DPP Meeting, Denver, USA, 11-15 Nov. 2013, GP8.00065.