§6. Nonlinear MHD Simulation of Collapse Event in a Helical System

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Nonlinear magneto-hydrodynamics (MHD) simulations are executed in a helical system with large pressure gradient to investigate the collapsing event which is induced by the MHD instabilities[1].

In recent experiments of the LHD, high performance confinement with a super-dense core (SDC) inside the internal diffusion barrier (IDB) has been achieved. On the re-heating stage in such a discharge, an abrupt flushing of the central density, termed as "core density collapse(CDC)", occurs in some cases. To reveal the mechanism of CDC is one of the key issues for further development of the confinement toward the high-density branch.

This simulation is executed in a helical plasma with large pressure gradient, which corresponds to the IDB-SDC state of LHD. The result obtained here would provide us with basic understandings for the collapse phenomena, including the CDC, from the point of view of MHD.

We solve the time development of the standard set of the compressive, resistive, nonlinear MHD equations in a full-toroidal three-dimensional geometry, by using the fourth-order central-difference scheme and the fourth-order Runge-Kutta method. To follow the geometry of the helical devices with continuously-wound magnetic coils of the LHD, we adopt the helical-toroidal coordinate system which is used in the HINT2[2] code. The initial condition for the simulation is also given by the HINT2 solution which roughly models the IDB-SDC state of LHD just before the CDC events with the maximum and the volume averaged beta value are 6.6% and 1.8%, respectively.

The simulation result shows the development of the ballooning-like instability mode with the dominant poloidal components $m\sim10$, which are localized in the outer region of the torus. The nonlinear long-term evolution of the energy and the maximum pressure is shown in Fig. 1. One can see that the growth and saturation of the energy repeats three times before reaching a relaxed state. During this relaxation process, the plasma changes its shape gradually.
The temporal changes in the poloidal pressure profile are shown in Fig.2. Since the primarily induced linear instability is localized in the outer region, the crash of the structures is first seen in the barrier region (see Fig.2(b)). The plasma surface is deformed, reflecting the linear eigenmode structures in the outer region, and part of plasma is lost due to the disturbance. The resultant pressure gradient in the barrier region becomes steeper than in the initial state. It should be noted that the mode structures of the instability are located only in the barrier region, whereas the central pressure gradually decreases, as the lost plasma forms a pedestal pressure in the edge region. If one sees the time development of the maximum pressure at the core as shown in Fig. 1, there is an abrupt change in the trace after t=335τ_A.

Other detailed analyses show that the rapid fall in the core pressure might be related to the change in the magnetic field structure. The magnetic surface structure is clearly formed entirely from the core to the edge region initially. Such a nested-surface structure is maintained during the early stage of the relaxation process, although the edge structure is markedly deformed, as shown in Fig. 2(b). At t=335τ_A, the magnetic surface structure abruptly diminishes throughout the whole poloidal cross section. However, the structure reappears in the core region immediately. This implies that the plasma in the core region at high pressure is linked to the external low-pressure region with an identical field line. Under this situation, the plasma outward flows due to the pressure imbalances along the field lines, which might cause the rapid fall of the core pressure, can be induced. The system reaches a relaxed state within 600τ_A in this result.

The simulation result can be compared qualitatively with the experimental observations on the CDC event in LHD. Our simulation results might provide us with interpretation for the unclear mechanisms for CDCs. Firstly, the fact that the core density decreases, keeping the core temperature unchanged, implies that the collapse is governed not by the conductive processes, but by the convective ones. In our simulation result, the core plasma is extracted convectively through the transiently disordered or reconnected field lines as described above. This convective loss mechanism is applicable even if no significant unstable mode exists in the core region. More detailed comparison would be our future works.

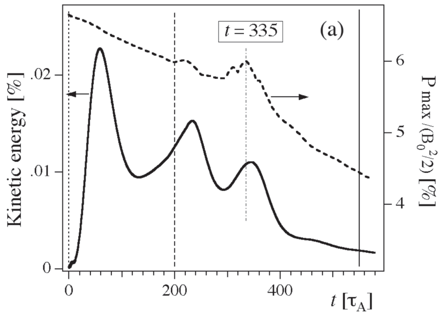

Fig.1 Time development of the energy and pressure.

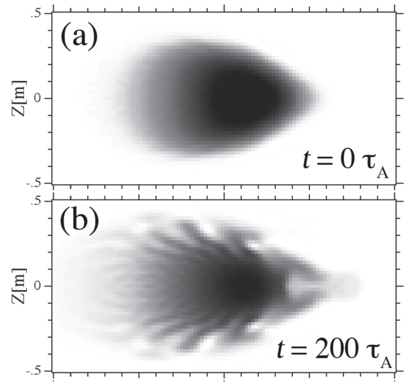

Fig.2 Change in the poloidal pressure profile.

1) N. Mizuguchi, et al., Plasma Fusion Res.(2008) (in print).
2) Y. Suzuki et al., Nucl. Fusion **46**, L19 (2006).