§1. Nonlinear Evolution of Ballooning Modes with Moderate Wavenumber in LHD

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Dynamical evolutions of ballooning modes with moderate wavenumbers in a fairly unstable plasma profile of the LHD are studied by means of fully three-dimensional MHD simulation by the use of the MINOS code.[1)] The initial plasma equilibrium is provided under the so-called inward-shifted magnetic configuration with the position of the magnetic axis Rax=3.6m. The pressure profile is given as $p(\psi) \approx P_0(1-\psi^2)$ where ψ is the toroidal magnetic flux function, and $P_0/(B_0^2/2) \approx 3.7\%$. (See Fig.1.) We have carried out a high-resolution full-3D simulation for the initial equilibrium in Fig.1 and have studied the dynamical growth of the ballooning modes up to $n \approx 15$.[2)]

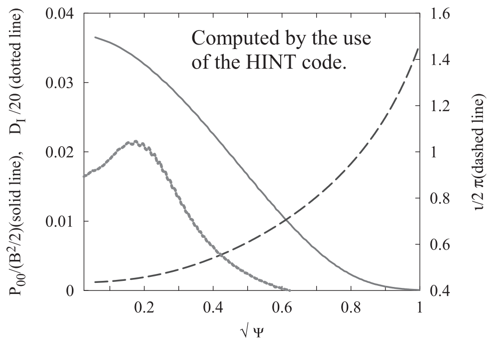

Fig. 1. Initial plasma profile. The red, pink and blue lines represent the pressure, D_I, and iota profiles, respectively.

In the simulation, the dissipative coefficients are provides sufficiently small so that the ballooning modes of $n \le 15$ (n is the toroidal wavenumber) grow without feeling influences of dissipations. In order to avoid numerical explosions, a numerical smoothing which acts as the fourth-order numerical viscosity is adopted.

The growth rates of the ballooning modes in the simulation are compared to those obtained by the linear and ideal MHD analysis (by the use of the CAS3D3 code) in Fig.2. The comparison shows that the two groups of the growth rates coincide to each other. We have also studied the radial profile of the ballooning modes and have found that the ballooning modes in our simulations coincide to those of the ideal MHD up to $n = 15$.

In the course of the time evolution, we observe that some ideal MHD mechanisms which can work to suppress the ballooning mode, such as the local pressure flattening, the compressibility effects, and the parallel flow generations. We have been paying special attention to the generation of the parallel flow, since the free-energy to drive the instability can be released in the parallel direction without destroying the plasma profile. Fig.3 is a typical observation of the parallel flow generation in the course of the time evolution in an early nonlinear stage of the time evolution. Strong parallel flows are generated on some rational surfaces.

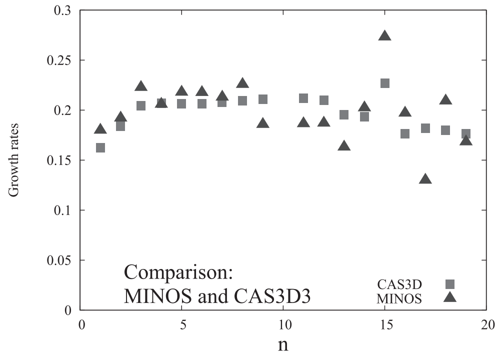

Fig. 2. A comparison of the growth rates of the MINOS simulation (triangles) to those of the CAS3D3 (boxes).

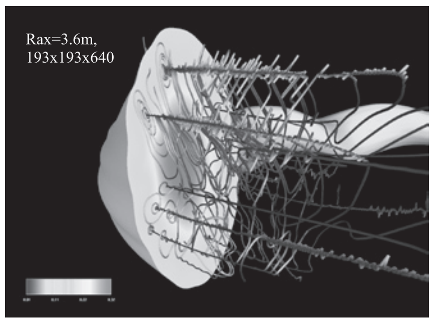

Fig. 3. Generation of strong parallel flow in the course of the time evolution. (At an early stage of the nonlinear stage.).

Although the three mechanisms work to weaken the impact of the ballooning modes, the plasma pressure experiences a large collapse in this simulation. On the other hand, in another simulation with a moderate value of the parallel heat conductivity which is not shown here, the ballooning modes are saturated relatively mildly. Comparisons of the two simulations are reported in the recent IAEA Technical Meeting on the theory of plasma instabilities[3)] and will be submitted soon.

The numerical simulations are carried out by NEC SX-7, the ex-“Plasma Simulator” and NEC SX-8 “LHD and numerical data analysis system”.

1) Miura, H. and Nakajima, N. IAEA 22th Fusion Energy Conference (13-18 October 2008, Geneva, Swithzerland) TH-P9/16.
2) Miura, H. et al., AIP.Conference Proceedings 871 (2006) pp. 157-168.
3) Miura, H. and Nakajima, N., the fourthe IAEA Technical Meeting on the Theory of Plasma Instabilities (May 18-20 2009, Kyoto, Japan) P1-08.