§3. Growth of High m/n Unstable Modes in 3D MHD Simulations LHD

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We have been carrying out direct numerical simulations of the fully three-dimensional, nonlinear MHD equations in the LHD geometry. One of our research purposes is clarifying the influences of growth of higher m/n unstable modes on lower modes. In the LHD, growth of fluctuations is considered to be dominated by interchange or ballooning instability in which higher modes have larger growth rates than lower modes. Althogh higher modes should grow faster than lower modes, the growth of the former has not been veryfied clearly and the influences of them on the nonlinear saturations of the instability are not clarified yet because of the lack of numerical resolutions. Though our earlier results have formal resolutions up to the toroidal Fourer wavenumber $n = 160$, the growth of the high modes are under influences of the viscosity. Consequently, the growth rates of the exponential growth are far from the growth rates obtained by the linear instability analysis.

Here we report our recent numerical results obtained by a high-resolution simulation to study the growth of high modes. An initial condition with the $\beta_0 = 3.7\%$ and $R_{ax} = 3.6m$ has been provided by using the HINT code[1]. Spatial derivatives are approximated by the 8th orde compact finite difference scheme. The 4th order Runge-Kutta-Gill scheme is applied for time-marching. We adopt the resistivity $\eta = 1 \times 10^{-6}$, the viscosity $\mu = 1 \times 10^{-6}$, the isotropic heat conductivity $\kappa = 1 \times 10^{-6}$, which are much smaller than the values adopted in our earlier work.[2] The simulations with these parameters are carried out for three sets of the grid points, 97×97, 193×193, and 385×385. It is found that the growth rates for $n > 10$ with the grid points 97×97 and 193×193 are influenced somewhat by the artificial viscosity. The computation with the largest number of grid points, 385×385 is now underway.

We decompose the velocity velctor into three components: parallel ($v^{\boldsymbol{b}}$), normal ($v^{\nabla\psi}$) and binormal ($v^{\nabla\psi\times\boldsymbol{b}}$). In Fig.1(a), time evolutions of the volume-integrated amplitudes of the three components. After identifying the exponential growth in Fig.1(a), each of the three components is decomposed into the Fourier coefficients associated with the poloidal and toroidal wavenumber m and n. In Fig.1(b), the Fourier amplitudes of $v^{\nabla\psi}$ are integrated over the poloidal wavenumber m and plotted for each n. The growth rates become larger for larger n. The $n = 15$ mode has the maximum growth rate. In Fig.2, contours (on a poloidal cross-section) and the isosurfaces of the pressure are shown. The isosurfaces are deformed by the growth of $m/n = 30/15$ unstable mode. The growth of the $m/n = 30/15$ mode shows that our simulation captures the short-wavelength instability property of the ballooning instabilty.

It is verified that growth of unstable modes up to $n = 15$ wavenumber is nearly ideal and influences of the viscosity (whether it is the molecular or the artificial) in the largest simulation with the number of grid points $385 \times 385 \times 640$. The influences of the higher modes on the lower modes will be studied through simulations with the same or larger number of grid points.

1) H. Harafuji, T. Hayashi and T. Sato, J. Comp. Phys., **81** (1989) 169.
2) H. Miura, N. Nakajima, T. Hayashi and M. Okamoto, Fusion Science and Technology **51** (2007) 1095.

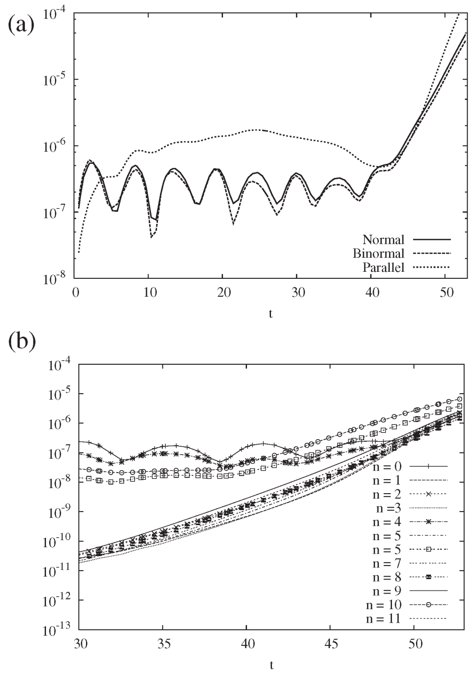

Fig. 1: (a)Time evolutions of the amplitudes of the three velocity componets. (b)Time evolutions of the Fourier-amplitudes of the normal component of the velocity.

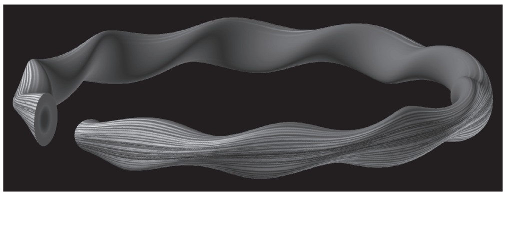

Fig. 2: Contours (on a poloidal cross-section) and the isosurfaces of the pressure.