§9. Nonlinear MHD Modes in Alfvén Eigenmode Evolution

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Nonlinear magnetohydrodymamic (MHD) effects on Alfvén eigenmode evolution were investigated via hybrid simulations of an MHD fluid interacting with energetic particles[1]. The investigation focused on the evolution of an n=4 toroidal Alfvén eigenmode (TAE) which is destabilized by energetic particles in a tokamak. In addition to fully nonlinear MEGA code, a linear-MHD version of MEGA code was used for comparison. The only nonlinearity in that linear code is from the energetic particle dynamics. No significant difference was found in the results of the two codes for low saturation levels, $\delta B / B \sim 10^{-3}$. In contrast, when the TAE saturation level predicted by the linear code is $\delta B / B \sim 10^{-2}$, the saturation amplitude in the fully nonlinear simulation was reduced by a factor of 2 due to the generation of zonal (n=0) and higher-n (n≥8) modes. This reduction is attributed to the increased dissipation arising from the non-linearly generated modes. The fully nonlinear simulations also show that geodesic acoustic mode is excited by the MHD nonlinearity after the TAE mode saturation.

The initial velocity-space distribution of the energetic ions is the slowing-down distribution with a maximum velocity $1.2\mathrm{v}_A$, where v_A represents the Alfvén velocity at the plasma center. The ratio of the energetic-ion Larmor radius to the minor radius a is 1/16 for the energetic-ion velocity equal to the Alfvén velocity. The aspect ratio is $R_0 / a = 3.2$. We focused on the evolution of an n=4 TAE mode. The MHD nonlinearity generates fluctuations with toroidal mode numbers multiples of 4 (n=0, 4, 8, 12, 16, …), while they are restricted only to n=4 in the linear-MHD simulation. The energetic-ion effect on the MHD fluid is restricted only to n=4 mode to clarify the nonlinear MHD effects. The evolution of MHD radial velocity $\mathrm{v}_r / \mathrm{v}_A$ measured at the TAE peak location is compared between the linear-MHD simulation and the nonlinear MHD simulation for the central energetic-ion beta value $\beta_{h0} = 1.7\%$. Different MHD dissipation coefficients, viscosity, resistivity, and diffusivity $\nu = \eta / \mu_0 = \nu_n = 10^{-6}\mathrm{v}_A R_0$, $2.5\times 10^{-7}\mathrm{v}_A R_0$, and $6.25\times 10^{-8}\mathrm{v}_A R_0$ were compared. For all the dissipation coefficients, we found that saturation level for the nonlinear MHD case is reduced to half of the linear-MHD case where the saturation amplitude predicted by linear-MHD simulation is $\mathrm{v}_r / \mathrm{v}_A \sim \delta B_r / B \sim 10^{-2}$.

This suggests that the saturation level would similarly reduce by the nonlinear MHD effects even if the parameters for more realistic dissipation were taken into account. We have analyzed the spatial profiles of the n=0 and n=8 fluctuations in the nonlinear MHD simulation. For the n=8 mode, the peak location of each poloidal harmonic is compared with the shear Alfvén continuum in Fig. 1(c). We can see that the peak location is on the continuum. This indicates that the dissipation of the n=8 mode arises from the continuum damping. This explains why the nonlinear damping takes place even for the weak dissipation cases, because the continuum damping is independent of the dissipation coefficients.

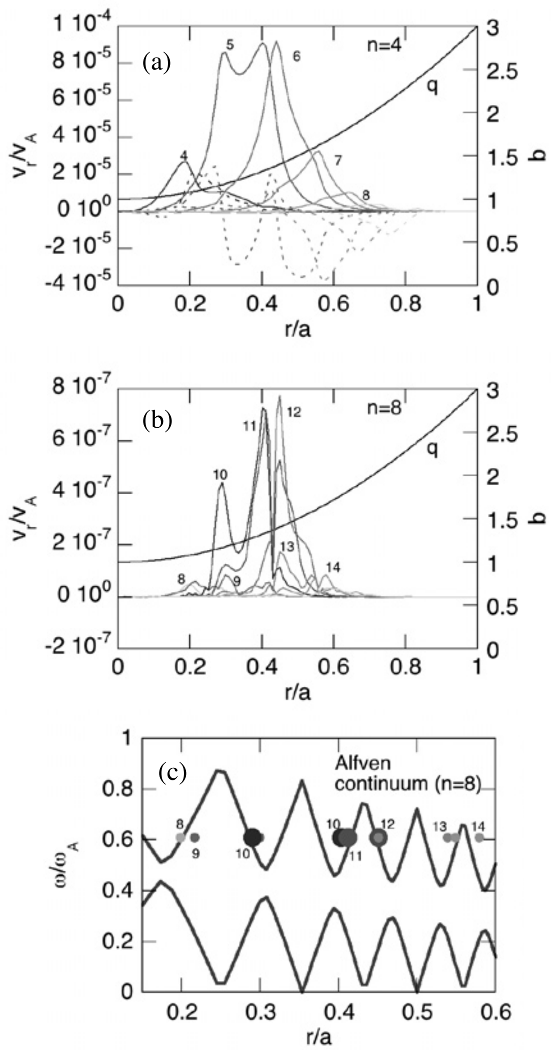

Fig. 1. Radial velocity profiles of the (a) n=4 and (b) n=8 modes, and (c) comparison of the peak location of each poloidal harmonic of the n=8 mode and n=8 shear Alfvén continuum.

1) Y. Todo, H. L. Berk, and B. N. Breizman, Nucl. Fusion **50**, 084016 (2010).