§6. Nonlinear MHD Effects on the Alfvén Eigenmode Evolution

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For time evolution of Alfvén eigenmodes, an important nonlinearity arises from the dynamics of energetic particles that destabilize the Alfvén eigenmodes. It was demonstrated by computer simulations that the particle trapping cause the saturation of toroidal Alfvén eigenmodes (TAE). This enables reduced simulations of TAE, where spatial profiles and damping rates of TAEs are assumed to be independent of mode amplitude. TAE bursts at a Tokamak Fusion Test Reactor experiment were reproduced by a reduced simulation [1]. Many aspects of the TAE bursts were well reproduced, while only the saturation amplitude was $\delta B/B \sim 2\times10^{-2}$ which is higher than the value $\delta B/B \sim 10^{-3}$ inferred from the experimental plasma displacement. In another simulation run of TAE bursts, where the MHD nonlinear effects are taken account, the saturation level is lower than $\delta B/B \sim 10^{-2}$ [2]. These simulation results motivate us to investigate the MHD nonlinear effects.

Two types of hybrid simulations of MHD fluid and energetic particles were carried out to investigate MHD nonlinear effects on Alfvén eigenmode evolution using MEGA code [3] and a linearized version of MEGA code. Fully nonlinear effects of both the MHD fluid and the energetic particles are contained in MEGA code. In the linearized version of MEGA code, the MHD equations are linearized while the nonlinear particle dynamics are followed.

The two types of simulation results were presented and compared [4]. A tokamak plasma, where a toroidal Alfvén eigenmode (TAE) with toroidal mode number n=4 is the most unstable, was investigated. Comparison between the results of the two types of simulations clarified the MHD nonlinear effects. We found that the saturation level is $\delta B/B \sim 8\times10^{-3}$ in the nonlinear MHD simulation results when the saturation level is $\delta B/B \sim 2\times10^{-2}$ in the linear MHD simulation results. The MHD nonlinear effects suppress the saturation level of the TAE. The results shown in Figs. 1 and 2 indicate that the nonlinear suppression effect arises from the change in n=0 harmonics of the magnetic field that is generated by the nonlinear electric field $-\mathbf{v}_{TAE}\times\delta\mathbf{B}_{TAE}$, a product of the velocity field and the magnetic field of the TAE. Axisymmetric velocity fields are also generated in the nonlinear run, although the change in the n=0 magnetic field plays the dominant role in the suppression of TAE. The effect of the n=0 harmonics of density variation will be investigated in the near future.

We have demonstrated that the MHD nonlinear effects suppress the TAE saturation level. It was also demonstrated by a computer simulation that the synchronized bursts of multiple TAEs take place with the MHD nonlinearity [2]. Thus, we can expect a simulation which reproduces the TAE bursts with saturation amplitude closer to that inferred from the experimental plasma displacement. On the other hand, energetic ion transport is also suppressed by the MHD nonlinearity. These results indicate that we need to focus on the feedback of the MHD fluid for the saturation level as well as beam ion transport in phase space when we try to simulate the TAE bursts.

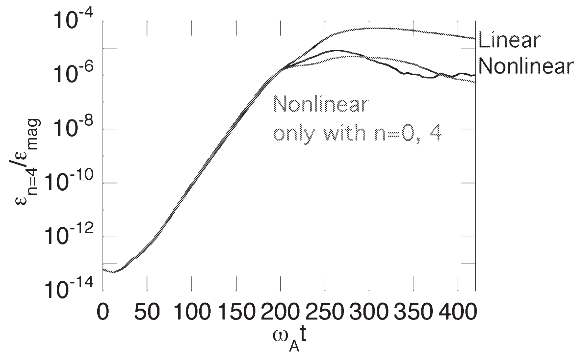

Fig. 1. Comparison of energy evolution of toroidal mode number n=4 between the standard nonlinear MHD run, the linear MHD run, and the nonlinear MHD run where only n=0, 4 modes are retained.

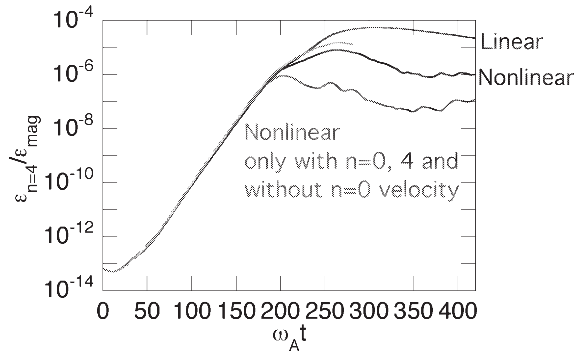

Fig. 2. Comparison of energy evolution of toroidal mode number n=4 between the standard nonlinear MHD run, the linear MHD run, and the nonlinear MHD run where only n=0, 4 modes are retained and the n=0 velocity field is removed. The curve between the linear and the standard nonlinear runs represents a run where only n=0, 4 modes are retained and the n=0 magnetic field is removed.

References
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[4] Y. Todo, H. L. Berk, and B. N. Breizman, “Nonlinear MHD Effects on the Alfvén Eigenmode Evolution”, in Proc. 9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems (Takayama, 2005) (NIFS-PROC-63, 2006), p. 79.