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Nonlinear Extended MHD Simulation of a Pressure-driven Mode with Two-fluid and/or Gyroviscous Effects
2流体効果、ジャイロ粘性効果を伴う圧力駆動型不安定性の非線形拡張MHDシミュレーション

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Numerical simulations of the Braginskii-type extended MHD equations are carried out to study two-fluid effects on pressure-driven unstable modes in magnetized plasma and their nonlinear dynamics. Two types of simulations, in a two-dimensional slab and in a three-dimensional geometry of the Large Helical Device (LHD), suggest that suppression of high-wave-number pressure-driven modes can cause longer growth of low-wave-number modes and can deteriorate the pressure profile considerably in comparison to simulations without the two-fluid and the gyro-viscous terms considerably.

1. Introduction

Growth and saturation of pressure-driven modes can endanger a confined state of magnetized plasma in a torus device. However, pressure-driven instabilities in the Large Helical Device (LHD) such as the interchange and the ballooning modes are often considered being saturated at a moderate level, without destroying the confined state definitely. Earlier studies on the moderate saturations have presented some possible mechanism such as the flattening of the pressure gradient, reduction of the growth rates due to the fluid compressibility, and the parallel flow generation to achieve the moderate saturation [1,2,3]. While these mechanism can play some finite roles in the saturation of the pressure-driven modes, one of our earlier works[2] shows that the proposed saturation mechanism is not necessarily sufficient to explain experimental results and we may need some mechanism outside the single-fluid MHD model.

For the purpose of finding some possibility for the saturation mechanism, we carry out two kinds of nonlinear extended magnetohydrodynamic (MHD) simulations, the Rayleigh-Taylor simulations in a two-dimensional (2D) slab and fully three- dimensional (3D) simulations of the ballooning- modes in LHD.

2. Rayleigh-Taylor simulation in a 2D slab

Firstly, we carry out simulations of the Rayleigh-Taylor-type instability in a 2D slab in order to obtain some insight on the nonlinear saturation of the growth of unstable modes. It is shown by the simulations that the growth rate of the unstable modes at high wave numbers are considerably suppressed in comparison to the single-fluid MHD simulation when the two-fluid and the gyro-viscous term are finite, although stabilization is incomplete as P. Zhu et al have shown earlier.[4] However, it is also found that the suppression of the growth rates at high wave numbers weaken nonlinear couplings among between unstable modes, and enhance the linear growth of low-wave-number unstable modes. Consequently, the impact of the growth of the unstable modes on the initial equilibrium pressure profile in the extended MHD simulation is as large as that in the single-fluid MHD simulation. In fact, some indices of the nonlinear growth of the unstable modes such as the mixing width and the saturation levels of the kinetic energy indicate a larger fluctuation of the pressure in the extended MHD simulation than that in the single-fluid MHD simulation [5].

3. Full 3D simulation in Large Helical Device

Secondary, we carry out full 3D simulations of the ballooning instability in LHD. Initial equilibrium of the vacuum magnetic axis R_{ax}=3.6m and beta0=3.7% is used for this study. It has been shown by the authors that the ballooning modes can grow to destroy the core pressure of the initial equilibrium. Here we carry out full 3D simulations with the two-fluid term. In order to suppress the computational cost, we neglect the gyroviscous term and add hyper-diffusivity of the fourth-order, mimicing suppression of the growth of high modes at high wave numbers by the gyroviscosity as we can see in the 2D R-T-type simulations in the above. The result of the numerical simulation with the two-fluid term and the hyper-diffusivity is compared to that of the single-fluid MHD simulations. (See Fig.1 for a typical view of a 3D simulation.) Inclusion of the two-fluid term can basically work either to suppress or to enhance the linear growth at high wave number modes, depending on the initial profile. However, in this case, it turns out that the two-fluid term enhances the growth of the unstable modes. Furthermore, the low wave number modes experience longer exponential growth than those in the single fluid MHD simulations. The numerical analysis shows that the suppression of the high wave number modes do not work to reduce the saturation level of the ballooning mode but work to bring about larger collapse of the plasma cores.

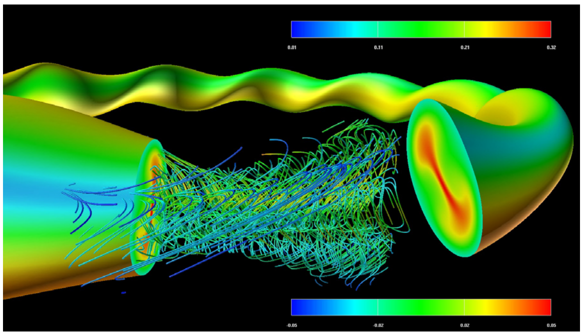

Fig.1. Growth of ballooning modes in a 3D simulation of LHD.

4. Concluding remarks

We have carried out two-kinds of simulations, the Rayleigh-Taylor instability in a 2D slab and full-3D ballooning instability in LHD. Both of the computations show that a simple suppression of the high wave number modes, whether by the two-fluid and the gyro-viscous term or by the two-fluid term and a hyper-diffusivity, can be insufficient to achieve moderate saturation of the pressure-driven modes. It suggests that further suppression of the unstable modes especially at low wave number modes can be vital for the mild saturations.

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