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VLASOV-MHD AND PARTICLE-MHD SIMULATIONS OF THE TOROIDAL ALFVÉN EIGENMODE

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Abstract

Two simulation codes, Vlasov-MHD code and particle-MHD code, are developed to elucidate nonlinear behavior of hybrid kinetic-MHD modes and energetic particles. Simulations of the toroidal Alfvén eigenmode (TAE mode) destabilized by energetic alpha particles are carried out. Vlasov-MHD simulation revealed that particle-trapping by a finite-amplitude wave causes the saturation. After saturation, amplitude oscillation takes place with a frequency corresponding to the bounce frequency of the alpha particles trapped by the TAE mode. Particle-MHD simulations are performed with more relevant condition to fusion plasmas, and saturation caused by particle-trapping is confirmed.

1. Introduction

In fusion reactors, successful confinement of alpha particles is required for self-sustained operation. The alpha particles born from D-T reactions are supposed to destabilize the macroscopic modes such as the toroidal Alfvén eigenmode (TAE mode) [1] and the fishbone mode. Nonlinear behaviors of such hybrid kinetic-MHD modes and alpha particles are one of the major physics uncertainties for fusion reactors. We have developed two simulation codes, Vlasov-MHD code [2] and particle-MHD code, to analyze hybrid kinetic-MHD modes. In both simulation codes the background plasma is described by an MHD fluid model, and the fully nonlinear MHD equations are solved by a finite difference method. In the Vlasov-MHD code the kinetic evolution of alpha particles is followed by the drift kinetic equation which is solved by a finite difference method, while the particle simulation method is used for the alpha particle component in the particle-MHD code. Alpha particle current except for **ExB** current is extracted from the total current in the MHD momentum equation to take into account the effects of alpha particles on the background plasma in a self-consistent way. Nonlinear kinetic effects such as the particle trapping by a finite-amplitude wave which suppresses the Landau damping can be followed by these codes. The Vlasov-MHD code has an advantage that it is free from numerical noises of particle discreteness, though it demands larger computer power than the particle-MHD code. On the other hand, the δf method [3-5] has been developed to reduce the numerical noises in particle simulations. We employ it in the particle-MHD code.

In the remainder of this paper, the plasma model is described in section 2. Vlasov-MHD simulations are carried out with a simplified alpha particle distribution and results are presented in section 3. Results of particle-MHD simulations with more realistic alpha particle distribution are given in section 4, and summary is given in section 5.

2. Plasma model

In the model employed here, the background plasma is described by the ideal MHD equations and the electric field is given by the MHD description. This is a reasonable approximation under the condition that the alpha density is much less than the background plasma density. The MHD equations are given by,

$$\frac{\partial \rho}{\partial t} = -\nabla\cdot\rho\mathbf{v}\,, \tag{1}$$

$$\rho\frac{\partial \mathbf{v}}{\partial t} + \rho\mathbf{v}\cdot\nabla\,\mathbf{v} = -\nabla p + \frac{1}{\mu_0}\nabla\times\mathbf{B}\times\mathbf{B}\,, \tag{2}$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla\times\mathbf{E}\,, \tag{3}$$

$$\frac{\partial p}{\partial t} = -\nabla\cdot p\mathbf{v} - (\gamma-1)p\nabla\cdot\mathbf{v}\,, \tag{4}$$

$$\mathbf{E} = -\mathbf{v}\times\mathbf{B}\,, \tag{5}$$

where μ_0 is the vacuum magnetic permeability and γ is the adiabatic constant, and all other quantities are conventional.

The drift kinetic description is used for the alpha particles. The guiding-center velocity v_D is,

$$\mathbf{v}_D = \mathbf{v}_{//}^{*} + \mathbf{v}_E + \mathbf{v}_B\,, \tag{6}$$

$$\mathbf{v}_{//}^{*} = \frac{v_{//}}{B}(\mathbf{B} + \rho_{//}B\nabla\times\mathbf{b})\,, \tag{7}$$

$$\mathbf{v}_E = \frac{1}{B}(\mathbf{E}\times\mathbf{b})\,, \tag{8}$$

$$\mathbf{v}_{\mathrm{B}} = \frac{1}{q_\alpha B}(-\mu\nabla B\times\mathbf{b})\,, \tag{9}$$

$$\rho_{//} = \frac{m_\alpha v_{//}}{q_\alpha B}\,, \tag{10}$$

$$\epsilon = \frac{1}{2}m_\alpha v_{//}^2 + \mu B\,, \tag{11}$$

$$m v_{//}\frac{dv_{//}}{dt} = \mathbf{v}_{//}^{*}\cdot(q_\alpha\mathbf{E} - \mu\nabla B)\,, \tag{12}$$

$$\frac{d}{dt}\mu B = \mu(\mathbf{v}_{//}^{*}\cdot\nabla B+\frac{\partial B}{\partial t})+ q_{\alpha}\mathbf{v}_{B}\cdot\mathbf{E}\,, \tag{13}$$

where μ is the magnetic moment which is the adiabatic invariant.

To complete the equation system in a self-contained way, we take account of the effects of the alpha particles on the bulk plasma in the MHD momentum equation,

$$\rho\frac{\partial\mathbf{v}}{\partial t} + \rho\mathbf{v}\cdot\nabla\mathbf{v} = (Q - Q_{\alpha})\mathbf{E} + (\frac{1}{\mu_0}\nabla\times\mathbf{B} - \mathbf{j}_{\alpha})\times\mathbf{B}-\nabla p\,, \tag{14}$$

$$\mathbf{j}_{\alpha} = \int \mathbf{v}_{D} f d^3v + \nabla\times\mathbf{M}\,, \tag{15}$$

$$\mathbf{M} = -\int \mu\mathbf{b} f d^3v\,, \tag{16}$$

where Q and Q_{α} are the total charge density and alpha particle charge density, and $\mathbf{j}_{\alpha}$ is the alpha particle current density. The total charge density Q is negligible in the MHD context where the quasi-neutrality is satisfied. Equation (14) is rewritten into the following form paying attention to that $-Q_{\alpha}\mathbf{E}$ cancels out with the Lorentz force of **ExB** currrent of alpha particles,

$$\rho\frac{\partial\mathbf{v}}{\partial t} + \rho\mathbf{v}\cdot\nabla\mathbf{v} = -\nabla p + (\frac{1}{\mu_0}\nabla\times\mathbf{B} - \mathbf{j}_{\alpha}')\times\mathbf{B}\,, \tag{17}$$

$$\begin{aligned}\mathbf{j}_{\alpha}' &= \int (\mathbf{v}_{//}^{*}+\mathbf{v}_{B}) f d^3v + \nabla\times\mathbf{M} \\ &= \mathbf{j}_{\alpha//} + \frac{1}{B}(P_{\alpha//}\nabla\times\mathbf{b}-P_{\alpha\perp}\nabla\ln B\times\mathbf{b}) + \nabla\times(-\frac{P_{\alpha\perp}}{B}\mathbf{b})\,.\end{aligned} \tag{18}$$

This model is the same as that of Park et al. [6] and the conservation of total energy is proved in Ref. 2.

2. Vlasov-MHD simulation

From Eqs. (6)-(13) we can obtain the drift kinetic equation which describes the time evolution of the alpha distribution function in the phase space (x, $v_{\|}$, μ),

$$\frac{\partial}{\partial t}f(\mathbf{x},v_{//},\mu) = -\frac{1}{B}\nabla\cdot(B\mathbf{v}_{D}f) - \frac{\partial}{\partial v_{//}}(\frac{dv_{//}}{dt}f) - f\frac{\partial}{\partial t}\ln B\,. \tag{19}$$

The Vlasov-MHD simulations have been carried out to elucidate the basic physics of the TAE mode saturation [2]. Due to the restriction of the present computer power, the magnetic moments of the alpha particles are set to be zero, namely, the phase space is reduced to 4-dimension (x, $v_{\|}$) and the drift kinetic equation is given by,

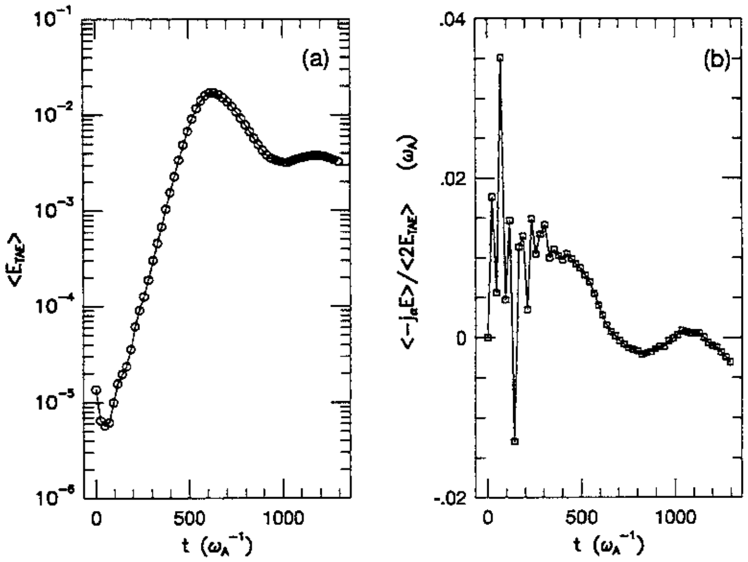

Fig. 1. Time evolutions of a) the TAE mode energy, and b) the ratio of the power transfer rate $<-\mathbf{j}_\alpha\cdot\mathbf{E}>$ to the TAE mode energy, which is divided by a factor of 2 to relate directly to the growth rate. The decrease of this ratio leads to the saturation of the TAE instability.

$$\frac{\partial}{\partial t}f(\mathbf{x},v_{//}) = -\nabla\cdot(\mathbf{v}_D f) - \frac{\partial}{\partial v_{//}}\left(\frac{dv_{//}}{dt}f\right). \tag{20}$$

The aspect ratio of the system is 3 and the poloidal cross section is rectangular. The cylindrical coordinate system (R, ϕ, z) is used. An axisymmetric equilibrium solution is obtained by an iterative method both for the MHD force balance and the distribution function of the alpha particles. The volume-averaged beta value of alpha particles $<\beta_\alpha>$ is 0.44%. We focus on the n=2 TAE mode and its nonlinear evolution including generation of n=0 modes. The most unstable n=2 TAE mode is excited, and the growth rate is agreeable with that of the linear theory [7].

In order to identify the saturation mechanism we analyze the time evolution of the power transfer rate from alpha particles to the MHD component, namely, $<-\mathbf{j}_\alpha\cdot\mathbf{E}>$ (< > means volume integration). We show the temporal evolution of the TAE mode energy in Fig. 1a and the ratio of the power transfer rate to the TAE mode energy (divided by a factor of 2 to relate directly to the growth rate) in Fig. 1b. At t=470 ω_A^{-1} the ratio begins to decrease, thus leading to saturation of the

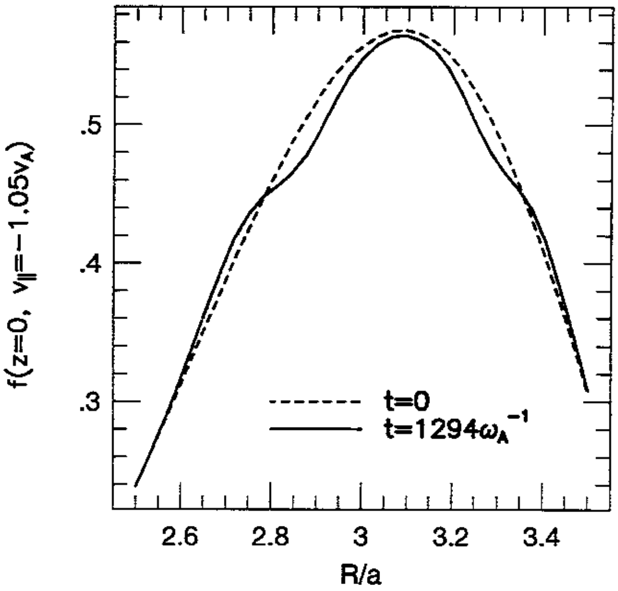

Fig. 2. The alpha particle distribution functions f(R) at $v_{\|} = -1.05 v_A$ and $z=0$ which are averaged in ϕ-direction and normalized by $f(v_{\|}=0, t=0)$ at the magnetic axis.

instability. It is evident that the decrease of the power transfer rate is the cause of the saturation. After saturation an amplitude oscillation occurs, of which frequency is 3 times larger than the linear growth rate. The frequency of the amplitude oscillation is consistent with the theory of the bounce frequency of particles trapped by the TAE mode [8].

Fig. 2 shows distributions of alpha particles at $v_{\|} = -1.05\ v_A$ and $z=0$ (midplane) as a function of R which are averaged in ϕ-direction at $t=0$ and $t=1294\omega_A^{-1}$, respectively. The spatial gradient of the distribution function is reduced to half near $R=2.8a$ and $3.3a$. The $m=0$, $n=0$ quasi-linear mode of the alpha particle distribution is generated through the nonlinear coupling between the $n=2$ TAE mode and the $n=2$ mode of alpha particle distribution. This quasi-linear mode spatially flattens the distribution function, removing the free energy source of the instability. Thus, we conclude that the saturation is caused by the particle trapping by the wave.

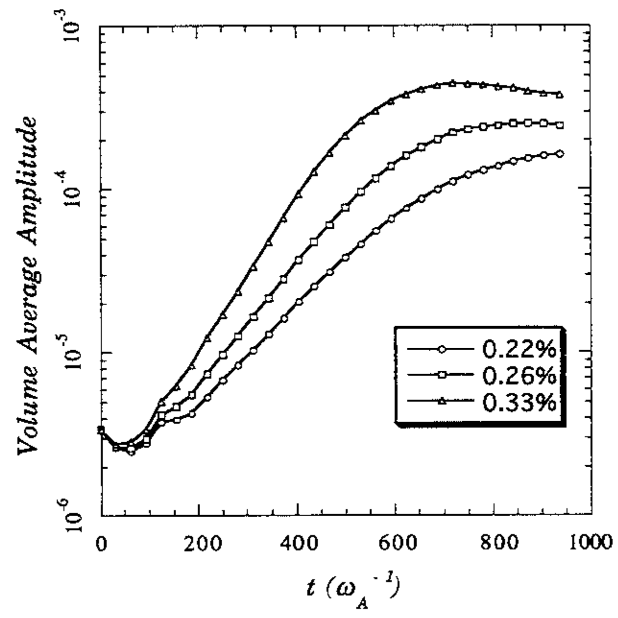

Fig. 3. Time evolution of volume average amplitude of n=2 TAE mode for $<\beta_\alpha>$=0.22%, 0.26%, and 0.33%.

4. Particle-MHD simulation

Saturation by **ExB** trapping was theoretically predicted in Ref. 9 and recently confirmed by computer simulations [2, 10, 11]. Nevertheless, no simulation took account both of realistic distribution of alpha particles and MHD nonlinearity. Realistic alpha particle distribution is indispensable to investigate alpha particle loss induced by TAE mode. In this section, we present the results of particle-MHD simulations which are carried out with more relevant condition to ignited plasmas. The initial alpha particle distribution is the slowing-down distribution which is isotropic in the velocity space with the maximum energy of 3.5 MeV. The magnetic field strength at the magnetic axis is 5T, the number density of the background plasma is 10^{20} m^{-3}, the minor radius is 0.9m, and the aspect ratio is 3.

For the alpha particle component, δf method is employed, which reduces the numerical noise in particle simulations. Using this method, $\mathbf{j}_\alpha'$ in equation (18) is evaluated through,

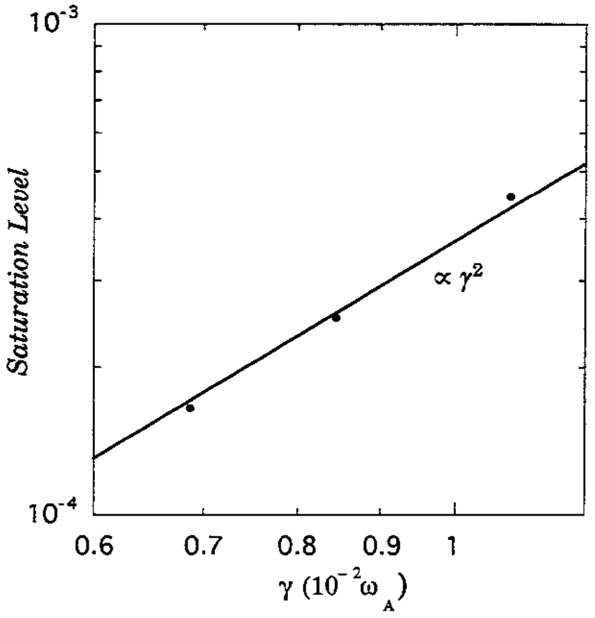

Fig. 4. Saturation level versus linear growth rate. Saturation level is in proportion to the square of linear growth rate.

$$P_{\alpha//} = P_{\alpha//0} + \sum_i w m_\alpha v_\parallel^2 S(\mathbf{x}-\mathbf{X}_i)\,, \tag{21}$$

$$P_{\alpha\perp} = P_{\alpha\perp 0} + B\sum_i w \mu S(\mathbf{x}-\mathbf{X}_i)\,, \tag{22}$$

where w is the weight and $S(\mathrm{x}\text{-}\mathrm{X}_i)$ is the shape function of each particle. The time evolution of w is described by [5],

$$\frac{d}{dt}w = -(1-w)\frac{d}{dt}\ln f_0\,, \tag{23}$$

where f_0 is the initial distribution. The initial distribution is taken to be a function of magnetic surface and energy.

For investigation of saturation of a single mode with the slowing-down distribution, we focus on the $n=2$ mode as well as in the Vlasov-MHD simulation. Time evolution of the volume average amplitude of the TAE mode for three different initial $<\beta_\alpha>$ is shown in Fig. 3. Saturation level is plotted against linear growth rate for three cases in Fig. 4. Saturation level is in proportion to the square of the linear growth rate. This relation supports the conclusion of Vlasov-MHD simulation that particle-trapping causes saturation. The ratio of lost particles to total alpha particles is typically 10^{-3}.

5. Summary

Vlasov-MHD and Particle-MHD simulations of the toroidal Alfvén eigenmode are carried out. These simulations demonstrate that saturation of a single mode is caused by **ExB** trapping. For multiple modes, it is theoretically predicted that overlapping of modes will lead to enhanced saturation level and stochastic diffusion of alpha particles [9, 12]. Simulations with multiple modes are under way and will be presented elsewhere [13].

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References

[1] CHENG, C. Z., CHANCE, M. S., Phys.Fluids **29** (1986) 3659.
[2] TODO, Y., SATO, T., WATANABE, K., WATANABE, T.-H., HORIUCHI, R., Phys.Plasmas **2** (1995) 2711.
[3] KOTSCHENREUTHER, M., Bull. Am. Phys. Soc. **34** (1988) 2107.
[4] DIMITS, A. M., LEE, W. W., J. Comput. Phys. **107** (1993) 309.
[5] PARKER, S. E., LEE, W. W., Phys. Fluids **B5** (1993) 77.
[6] PARK, W., et al., Phys. Fluids **B4** (1992) 2033.
[7] FU, G. Y., VAN DAM, J. W., Phys. Fluids **B1** (1989) 1949.
[8] BERK, H. L., BREIZMAN, B. N., YE, H., Phys. Fluids **B5** (1993) 1506.
[9] BREIZMAN, B. N., BERK, H. L., YE, H., Phys. Fluids **B5** (1993) 3217.
[10] FU, G. Y., PARK, W., Phys. Rev. Lett. **74** (1995) 1594.
[11] WU, Y., WHITE, R. B., CHEN, Y., ROSENBLUTH, M. N., Phys. Plasmas **2** (1995) 4555.
[12] BERK, H. L., BREIZMAN, B. N., PEKKER, M., Phys. Plasmas **2** (1995) 3007.
[13] TODO, Y., SATO, T., THE COMPLEXITY SIMULATION GROUP, *in preparation*.

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