21PA-030

Particle simulation of the flute instability in the low density plasma

低密度プラズマにおけるフルート不安定性の粒子シミュレーション

R.Kubota, I.Katanuma, G.Oda
窪田遼人, 片沼伊佐夫, 小田弦之介

Plasma Research Center, University of Tsukuba
プラズマ研究センター, 筑波大学

I. INTRODUCTION

The high temperature ions are produced in the anchor cell by using ion cyclotron radio frequency (ICRF) heating to control outbreak of the flute instability in GAMMA10. In addition, it is revealed that the flute instability surely occurs and cannot maintain plasma experimentally when the quantity of high temperature ions decreases. By the way, electron cyclotron resonance discharge cleaning (ECR-DC) is performed for the purpose of cleaning the wall before the main experiment in GAMMA10 which generates low density plasma there. Though there is no high temperature ions in the anchor cell as for this low density plasma, it is stable in GAMMA10. The purpose of this study is to clarify the stability in a low density domain predicted by a linear theory using particle simulation.

II. LINEAR THEORY OF THE FLUTE INSTABILITY

In the linear theory, the dispersion equation is obtained as following equation.[1]

$$\frac{\partial}{\partial x}\left(\epsilon_\perp \frac{\partial \psi}{\partial x}\right) - k_y^2 \epsilon_\perp \psi + \frac{k_y}{\omega_{ci}} \frac{k_y g/\omega_{ci}}{\omega(\omega + k_y g/\omega_{ci})} \frac{d\omega_{pi}^2}{dx} \psi = 0 \quad (1)$$

Here, $\psi, k_y, g, \omega_{ci}, \omega_{pi}$, and $\epsilon_\perp$ are potential, wave number, centrifugal acceleration, ion cyclotron frequency, ion plasma frequency, and plasma dielectric response function ($\epsilon_\perp = 1 + (\omega_{pi}/\omega_{ci})^2$). The linear growth rate of a flute instability is calculated by solving this equation. However it does not agree with simulation in the low density domain. The flute mode is predicted to be stable in such domain in the linear theory, but it was found not stable in simulation. So Eq.(1) may be not suitable and it seems impertinent treatment of an approximation.

In Eq.(1), $\omega \gg k_y g/\omega_{ci}$ is assumed as additional approximation. This means that the flute instability is significantly slower phenomena than ion cyclotron frequency. Thereby, Eq.(1) should reduces to the following equation.

$$\frac{\partial}{\partial x}\left(\epsilon_\perp \frac{\partial \psi}{\partial x}\right) - k_y^2 \epsilon_\perp \psi + \frac{1}{\omega^2} \frac{k_y^2 g}{\omega_{ci}^2} \frac{d\omega_{pi}^2}{dx} \psi = 0 \quad (2)$$

Linear growth rates derived from Eq.(2) don't become 0 and show good agreement with simulation.

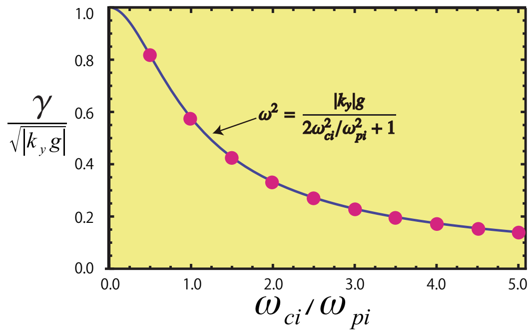

Figure 1: Linear growth rates of the flute instability when density distribution is step function. The red circles are obtained from Eq.(2).

Figure 1 plots the linear growth rates of the flute instability in case of $k_y g/\omega_{ci}^2 = 10^{-4}$, which was obtained by solving Eq.(2) in the range of $0 \le k_y x \le 4\pi$ with the boundary condition that $\psi = 0$ at $k_y x = 0$ and $k_y x = 4\pi$. The vertical axis γ in Fig.1 is the linear growth rate of the flute instability, i.e., $\omega = \omega_r + i\gamma$, where i is the imaginary unit. If the density profile is step function $n(x) = n_0[1 - \theta(x)]$, the dispersion relation becomes[2] $\omega^2 = -|k_y|g/(2\omega_{ci}^2/\omega_{pi}^2 + 1)$ which is plotted in Fig.1. Figure 1 indicates that Eq.(2) includes this well-known dispersion relation, and linear growth rates become smaller in the low density domain.

On the other hand, in this paper,

$$n(x) = -a \tanh\left(\frac{x - L_x/2}{a_h}\right) + b$$

is adopted as a density distribution (Fig.2). Here, a,b are constant, $L_x(= 256)$ is system size in x-direction, and a_h is characteristic length.

III. SIMULATION RESULTS

This paper uses the uniform gravitational field $\boldsymbol{g} = g\hat{e}_x$ shown in Fig.2, where $\hat{e}_x$ is the unit vector along x-axis. The uniform external magnetic field $\boldsymbol{B} = B\hat{e}_z$ is applied along z-axis. Ions and electrons are distributed as hyperbolic tangent function for x direction at $t = 0$.

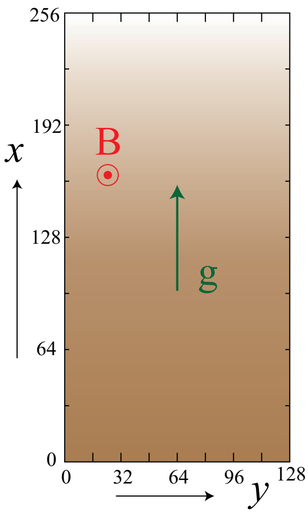

Figure 2: Initial density distribution $n(x) = -a\tanh(\frac{x-L_x/2}{a_h}) + b$, gravitational acceleration vector $\boldsymbol{g}$, and external magnetic field.

The code uses two-dimensional 256×128 spatial meshes in $x - y$ and three velocity components v_x, v_y, and v_z. $(9 \times 256 \times 128)$ ions and electrons each are used in the simulation.

The flute instability is observed in the simulation because the geometry Fig.2 is unstable to the flute modes. Figure 3 plots the linear growth rates of the flute instability with (1,1) mode measured in the linearly growing phase of the simulation. The solid circles in Fig.3 are simulation results. The solid line is the theoretically calculated linear growth rate Eq.(2). The simulation parameters that $m_i/m_e = 1830$, $k_y g/\omega_{ci}^2 = 10^{-4}$, and the solid circles in Fig.3 were obtained by changing the electron cyclotron frequency ω_{ce}/ω_{pe}.

The agreement between theory and simulation is good in Fig.3. It is not good in the low density domain if Eq.(1) was used to calculate linear growth rates because it becomes 0 at $\omega_{ci}/\omega_{pi} \sim 65$. Thus, it seems that Eq.(1) in the Ref.1 is not suitable, and Eq.(2) is better linear dispersion equation than Eq.(1).

The time evolutions of field energy $|\boldsymbol{E}|^2$ of (1,1) mode are plotted in Fig.4. Like Fig.3, it is found that linear growth rate of the flute instability becomes small if ω_{ci}/ω_{pi} becomes large.

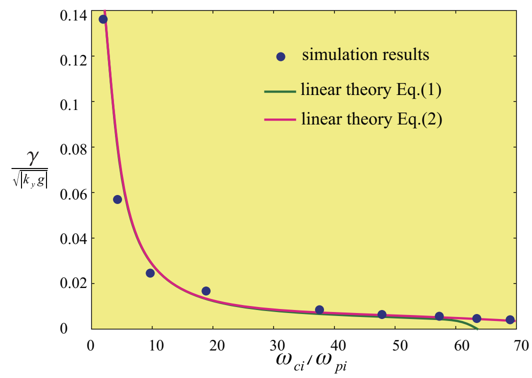

Figure 3: Linear growth rates of the flute instability as a function ω_{ci}/ω_{pi} means reciprocal function of the density.

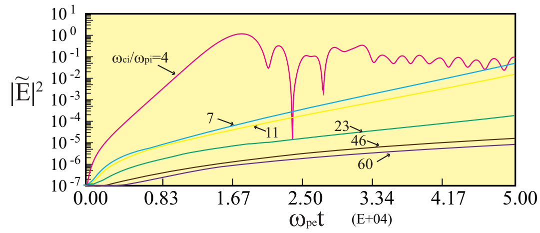

Figure 4: Time evolution of field energy of (1,1) mode.

IV.CONCLUSIONS

The flute instability in the geometry of Fig.2 were investigated by using electrostatic implicit PIC code. The linear growth rates of the flute instability in the particle simulation agree well with the theoretical linear growth rate Eq.(2). It seems that Eq.(1) in the Ref.1 is not suitable for investigating the flute instability in the low density plasma.

It is found that the flute instability has a tendency of stabilization in the low density plasma. Although it is not completely stabilized, the linear growth rate of the flute instability is very small compared with high density plasma.

References

[1] A. B. Mikhailovskii, *Theory of Plasma Instabilities*, (I. V. Kurchatov Institute of Atomic Energy Moscow, USSR, 1971).

[2] For example, K. Miyamoto, *Plasma Physics for Nuclear Fusion*, (MIT Press, Cambridge, MA, 1979).