EXCITATION OF AN ELECTROSTATIC ION BERNSTEIN WAVE BY AN ION BEAM IN PLASMA WITH DENSITY RIPPLED

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ABSTRACT

Ion Bernstein instabilities can occur in ion beams. The ion Bernstein wave can be effectively excited by an ion beam. Ion cyclotron waves with a lower parallel phase velocity may be driven by the ion beam through Cerenkov interaction, while ion Bernstein waves have a large parallel phase velocity. When the transverse wave number of waves becomes inverse of the Larmor radius, each mode's maximum growth rate will be determined. The discussion and graphical results show that the density ripple and static magnetic field increase the wave growth rate. This theory of ion Bernstein wave excitation may be applicable to fusion plasma.

KEYWORDS: Ion Bernstein wave, Ion cyclotron wave, Ion beam, Cerenkov interaction, Larmor radius

1. INTRODUCTION

In last several decades, the ion Bernstein waves play an important role in radio frequency heating of tokamak. Ion Bernstein wave is a particular type of electrostatic wave that possess short wave length in plasma embedded with static magnetic field. A large amplitude of ion Bernstein wave can strongly couple with the low frequency turbulence and hence affects the plasma transport property [1]. Kumar and Tripathi have studied the ion Bernstein wave excitation in a plasma column by using a gyrating ion beam. Here, the growth rate becomes maximum as the Landau damping is taken into consideration [2].

Theoretically and experimentally studied the excitation mechanism of ion Bernstein wave. Reynolds and Ganguli [3] theoretically investigated a scheme of ion Bernstein wave excitation by using the two transverse flow layers of plasma. They found that when the two flow layers of plasma are close, the coupling of becomes too strong. In tokamak reactor core, the ion Bernstein wave plays a crucial role for radio frequency heating via finite-Larmor-radius mode [4-5]. Ram and Schultz have studied the electron Bernstein wave excitation in tokomak via mode conversion of extra ordinary and ordinary waves. Here, the two-mode conversion effectively excites this electrostatic wave near the Doppler broadened resonance [6]. Energetic electrons beam has much potential to excite the extraordinary Bernstein wave via thermal extraordinary instability [7]. Ion Bernstein wave is excited by linear mode conversion theory of fast wave during the current drive experiment. The resonant excitation of wave was observed due to Landau damping [8-9]. In tokomak Fusion Test Reactor, as the fast energetic ion beam interacts with electrostatic ion Bernstein wave, lost ions were observed lost ions with enormous heating upto several MeV. The ion Bernstein wave is excited in tokamaks via mode conversion process and the mode conversion attains the very small poloidal phase velocity [10].

In this paper, we theoretically excite the ion Bernstein waves by the interaction of an ion beam with rippled density plasma. The theoretical formalism of growth rate of ion Bernstein wave is discussed in Sec. 2. The results and discussion of this study is presented in Sec. 3. Finally, in Sec. 4, summary and conclusion is included.

2. ION BERNSTEIN WAVE

Consider a rippled density plasma of equilibrium electron density $n_e = n_{0p} + n_{q,} n_q = n_{0q}e^{iqz}$ immersed in a static magnetic field $\vec{B}_s \parallel \hat{z}$. An ion beam of equilibrium density n_{0b} propagates through the plasma with equilibrium velocity $\vec{v}_{0b} \parallel \hat{z}$.

We perturb the equilibrium by an ion Bernstein wave of electrostatic potential

$$\phi_{\omega,\vec{k}} = A_{\boldsymbol{\omega},\vec{\boldsymbol{k}}}e^{-i(\omega t-k_x x-k_z z)} \tag{1}$$

Due to the presence of the density ripple, electrostatic potential also has a component $\phi_{\omega,\vec{k}+\vec{q}}$.

A. PLASMA ION RESPONSE

The velocity perturbation of plasma ions $\vec{v}_{\omega,\vec{k}}$ due to $\phi_{\omega,\vec{k}}$ can be written as

$$v_{x,\omega,\vec{k}} = \frac{2e}{m_i v_{th}^2}\frac{\omega_{ci}^2}{(\omega-l\omega_{ci})k_\perp}\left[-l(l+1)I_l(b_i)e^{-b_i} + \frac{2v_{thi}k_\perp}{\omega_{ci}}I_A + I'\right]\phi_{\omega,\vec{k}}, \tag{2}$$

B. ELECTRON RESPONSE

The electron density perturbation due to ion Bernstein wave at $\omega, \vec{k}$ is

$$n_{e,\omega,\vec{k}} = \frac{k^2\epsilon_0}{e}\chi_{e,\omega,\vec{k}}\phi_{\omega,\vec{k}}, \tag{3}$$

where $\chi_{e,\omega,\vec{k}} = -\frac{\omega_p^2}{k^2}\left(\frac{k_z^2}{\omega^2} - \frac{k_\perp^2}{\omega_c^2}\right)$ for $\omega \gg k_z v_{the}$,

The electron density perturbation due to ion Bernstein wave at $\omega, \vec{k}+\vec{q}$ is

$$n_{e,\omega,\vec{k}+\vec{q}} = \frac{\{k_x^2 + (k_z+q)^2\}\epsilon_0}{e}\chi_{e,\omega,\vec{k}+\vec{q}}\,\phi_{\omega,\vec{k}+\vec{q}}\,, \tag{4}$$

C. BEAM RESPONSE

The response of beam ions to the electrostatic perturbation is governed by the equation of motion,

$$\frac{\partial\vec{v}_b}{\partial t} + (\vec{v}_b\cdot\nabla)\vec{v}_b = \frac{e}{m_b}\left(\vec{E}_{\omega,\vec{k}} + \vec{v}_b\times\vec{B}_s\right), \tag{5}$$

where, m_b is the ion mass of the ion beam, $\vec{E}_{\omega,\vec{k}} = -\nabla\phi_{\omega,\vec{k}}$ and $\vec{v}_b = v_{0b}\hat{z} + \vec{v}_{b,\omega,\vec{k}}$.

D. GROWTH RATE

The growth rate of Ion Bernstein wave can be written as

$$\gamma = \left[\frac{\left((k_x^2/k^2)\omega_b^2\right)}{2\omega_{cb}}\cdot\frac{1}{\left(\frac{\partial F}{\partial\omega}\right)_{\omega=\omega_R}}\right]^{1/2} \tag{6}$$

3. RESULTS AND DISCUSSION

We have carried out the numerical calculations for the growth rate of ion Bernstein wave. In Fig. 1, we have plotted the variation of growth rate as a function of ion Bernstein wave frequency for different values of normalized ion thermal velocity $k_{\perp}v_{thi}/\omega_{ci}$. The normalized growth rate of ion Bernstein wave is rapidly decreased as one increases the ion Bernstein wave frequency. It can be noticed that as the normalized ion thermal velocity is increased, the growth rate of ion Bernstein wave increases. The increased ion thermal velocity results the energized ion and this energized ion leads to increase the growth rate of ion Bernstein wave.

In Fig. 2, the variation of normalized growth rate of ion Bernstein wave as a function of normalized ion Bernstein wave frequency for different values of normalized beam cyclotron frequency ω_{cb}/ω_{ci} is plotted. It can be noticed that as the normalized beam cyclotron frequency is increased, the normalized growth rate of ion Bernstein wave increases. The beam cyclotron frequency is directly proportional to the static magnetic field. Since, we know that the confinement and alignment of charge particle will take place with increase in the strength of magnetic field in the plasma and which leads to much more excitation of ion Bernstein wave. This results that as the strength of static magnetic field is increased, the normalized growth rate of ion Bernstein wave will be increased.

Figure 1: The variation of normalized growth rate as a function of normalized ion Bernstein wave frequency for different values of $k_{\perp}v_{thi}/\omega_{ci}$ in the case of Cerenkov interaction. The parameters are: $\omega_{cb}/\omega_{ci} = 1$, $\omega_q/\omega_{ci} = 0.3$, $\omega_b/\omega_{ci} = 1.5$, $k_z v_{thi}/\omega_{ci} = 0.5$, $qv_{thi}/\omega_{ci} = 1.5$, $v_{0b}/v_{thi} = 20$, $\omega_c/\omega_{ci} = 4000$ and $v_{the}/v_{thi} = 200$

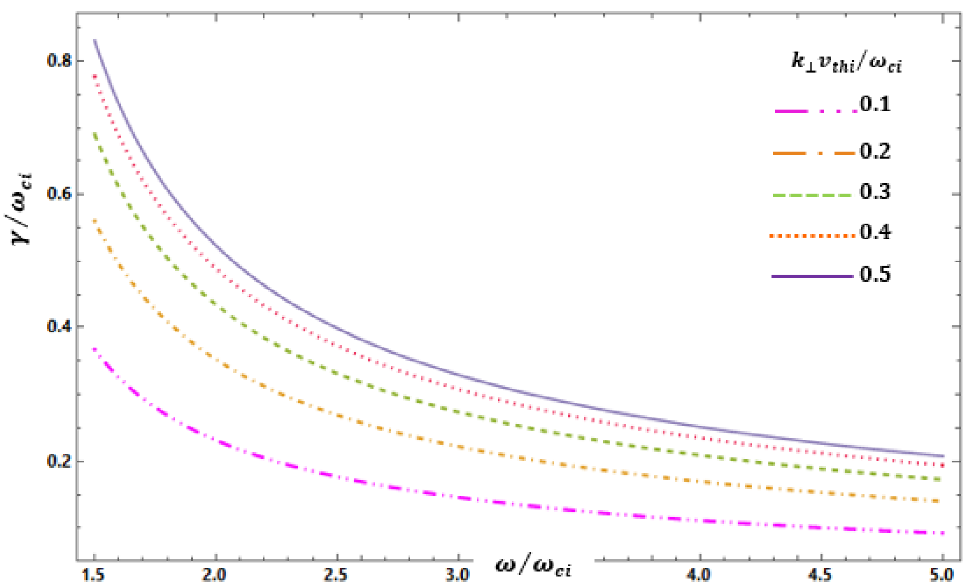
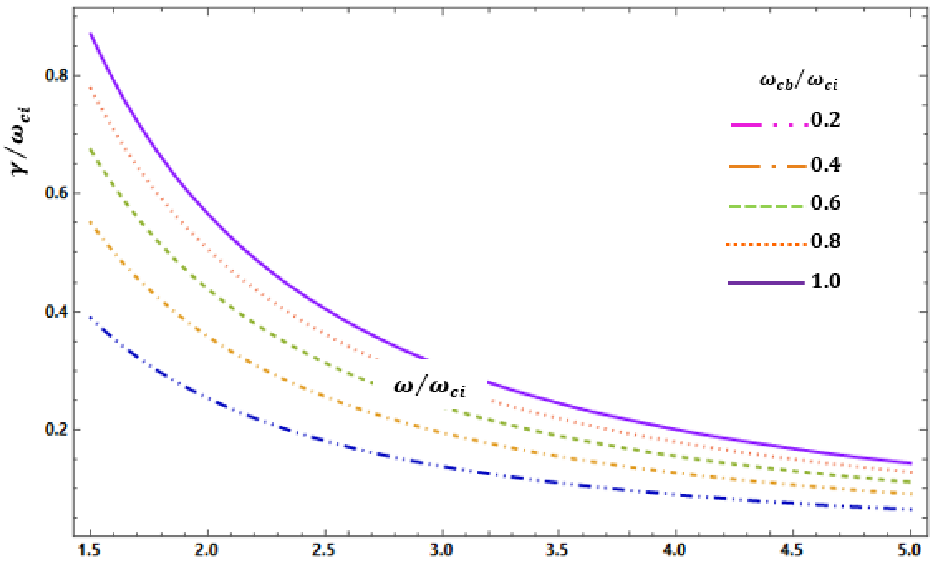


Figure 2: The variation of normalized growth rate as a function of normalized ion Bernstein wave frequency for different values of ω_{cb}/ω_{ci} in the case of slow cyclotron wave. The parameters are: $k_{\perp}v_{thi}/\omega_{ci} = 10$, $\omega_q/\omega_{ci} = 0.1$, $\omega_b/\omega_{ci} = 0.4$, $k_z v_{thi}/\omega_{ci} = 0.01$, $qv_{thi}/\omega_{ci} = 1.5$, $v_{0b}/v_{thi} = 20$, $\omega_c/\omega_{ci} = 4000$ and $v_{the}/v_{thi} = 200$.



4. SUMMARY AND CONCLUSION

In this paper, we study the excitation of ion Bernstein wave via the interaction of an ion beam with rippled density plasma. The Vlasov theory is used to obtain the response of ion beam with ion Bernstein wave. The growth rate of ion Bernstein wave is obtained via Cerenkov interaction and slow cyclotron interaction . The obtained growth rate of these waves was found maximum as the wave number becomes inverse of Larmor radius. The growth rate of wave is dependent on ion thermal velocity and rippled density of plasma. This excited scheme of ion Bernstein wave might be relevant in fusion plasma and parametric instabilities.

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