ORIGINAL RESEARCH ARTICLE

EXCITATION OF ELECTRON BERNSTEIN WAVE BY ELECTRON BEAM IN MAGNETIZED PLASMA WITH NON-MAXWELLIAN DISTRIBUTION

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ABSTRACT:

We have developed a nonlocal theory for the excitation of electron Bernstein waves in a magnetized plasma slab using a relativistic electron beam, considering the distribution function of the loss cone velocity. The kinetic theory is employed to solve the equation of motion and the beam response to the Bernstein wave field. The mode structure and growth rate of the electron Bernstein wave are determined within the WKB approximation limits. The growth rate in the case of Cherenkov and slow cyclotron interactions in an infinite medium is proportional to ω_b0^(1/3) and ω_b0, respectively. The normalized growth rate attains a maximum value at b ≈ 1.743 for different normalized beam velocities. These parameters control the growth rate due to nonlocal effects, and this effect rapidly decreases. The present theoretical model may find potential application in the field of spherical torus plasmas.

KEYWORDS: Electron Bernstein Wave, Magnetized Plasma, Loss Cone Velocity Distribution Function, Growth Rate, Slow Cyclotron Interaction.

INTRODUCTION:

In last few decades, many researchers have been investigated the linear and non-linear excitation of relativistic as well as non-relativistic electron Bernstein wave (EBW) in magnetized beam plasma [1-6]. The application of highly energetic excited relativistic electron beam has found in many areas such as science and technology which impinges scientist to study the electron cyclotron wave (ECW) which propagate in high frequency WKB approximate limit [7-8]. The outstanding importance of this excited EBW than the general electromagnetic wave which consists of ordinary and extraordinary waves because the later cannot be penetrating in the case of over dense plasma [9]

Distribution function which has small perpendicular velocity and having deficiency of particles is term as loss-cone distribution function which also previously famous as Dory– Guest–Harris distribution function [10]. The velocity dependent of this distribution function termed as Kappa distribution function [11]. This function has been found very useful tool for the theoretically study of instabilities analysis in electrostatic and electromagnetic waves which applicable in solar wind, ring current plasma and magneto sheath [12-14]. In this paper we have theoretically generalize the formalism of Jain and Tripathi [1] for the study of electron Bernstein wave excitation mechanism by relativistic electron beam with taking loss cone velocity distribution function in plasma slab. The plasma slab has been taken parabolic profile with the axis x extent and the static magnetic field in z direction which is transverse with each other. The plasma profile with x extent depends on density scale length. The localization of Bernstein mod is governed by the value of x as $k_x = 0$ and this point is the turning point for this wave. A relativistic electron Bernstein wave with loss cone velocity distribution having uniform density and scale length is assumed to propagate along the z- axis with drift velocity $v_b\hat{z}$ in to the plasma. For the analysis of the beam response to the Bernstein wave famous formalism Vlasov theory have taken in to account.

The beam response, and growth rate have discussed in section 2 and 3 respectively. The discussion and conclusions have discussed in section 4.

2. BEAM RESPONSE IN INHOMOGENEOUS PLASMA

We have considered the plasma slab consisting of majority species of electrons and the slab have large length in z extent. The electrons caries least masses exhibit the characteristics correlation potential. The boundary of plasma is to be taken as the $x = \pm R$ with its density profile non-uniform as taken parabolic and we assumed an axial magnetic field with z- direction present in the plasma slab. When a relativistic electron beam is passed through this plasma slab, the exiting magnetic field cause to produce cyclotron frequency by which one get Larmor radius. When this Larmor radius of electron beam is much smaller than the x extent of plasma slab, then the larger extent of x dimension dominate this Larmor radius and this electron response can be ignored. Since we know that the electron Bernstein beam is a special type of cyclotron wave whose frequency is much close to cyclotron frequency having much large part of perpendicular wavenumber $k_\perp$ than the parallel wavenumber $k_\parallel$. Hence, we can consider the electrostatic potential of a Bernstein wave with harmonic potential.

$$\emptyset = \emptyset_0 e^{-i(\omega t - \boldsymbol{k}.\boldsymbol{r})}, \tag{1}$$

Where ω and k is the frequency and wave vector respectively.

The equation of beam Plasma is govern by

$$m\left[\frac{\partial}{\partial t}(\gamma_r\vec{v}) + \vec{v}.\nabla.(\gamma\vec{v})\right] = e\vec{E} - \frac{e}{c}\vec{v}\times\vec{B}, \tag{2}$$

and Vlasov equation is given by

$$\frac{\partial f}{\partial t} + \vec{v}\nabla f - \frac{e}{m}(\vec{E} + \vec{v}\times\vec{B}).\frac{\partial f}{\partial t} = 0, \tag{3}$$

3. GROWTH RATE

Now, for evaluating of growth rate (γ) caused by the beam in the weak beam approximation and slow cyclotron interactions, taking ω to be complex ($\omega = \omega_r + i\gamma = \omega_r + \Omega$).

For the case of Cerenkov interaction we substitute $\omega_r = k_\parallel v_{ob}$ and taking the mode $q = 0$, we obtain the growth rate

$$\mathrm{Im}\Omega = \gamma = \left[\frac{\omega_{bo}\omega_c^2 N_0{}^2 k_\parallel^2}{\omega_p^2\beta^{1/2}D\delta\gamma_0^3}\right]^{1/3} \times \left[\sqrt{\pi}\,\mathrm{erf}(a')\left(1 - \frac{1}{2a'^2}\right) + \frac{1}{a'}\exp\left(-2a'^2\right)\right]^{1/3} \times \frac{\sqrt{3}}{2}, \tag{4}$$

For the slow cyclotron interaction, we substitute the $\omega = \omega_r + i\gamma = \omega_r + \Omega$ and $\omega_r \approx k_\parallel v_{ob} + \frac{\omega_c}{\gamma_0}$.

Assuming $\gamma/\omega_c \ll 1$, the expression for growth rate is

$$\mathrm{Im}\Omega = \gamma = \left[\frac{\omega_{bo}\omega_c^2 N_0{}^2 k_\perp^2}{\omega_p^2\beta^{1/2}D\delta}\right]^{1/2} \times \left[\sqrt{\pi}\,\mathrm{erf}(a')\left(1 - \frac{1}{2a'^2}\right) + \frac{1}{a'}\exp\left(-2a'^2\right)\right]^{1/2} \times \frac{\sqrt{3}}{2}, \tag{5}$$

Where erf is the error function and parameter a' is defined as

4. DISCUSSION AND CONCLUSION

In the beginning we have solved with coupled the equation of beam and Vlasov equation. With this one could find the beam dielectric susceptibility expression. Further employing the loss cone velocity distribution function in the equations of motion, dielectric susceptibility function for plasma has derived. In this model waves parabolic profile with finite limiting range with existing value at $x < a$ and vanishes at $x > a$.

In fig.1. we have plotted graph between the normalized growth rate $\frac{\gamma}{\omega_c}$ as a function of b. The typically value of normalized parameter are chosen as $\omega_p/\omega_c = 1$, $\omega_{pb}/\omega_c = 0.1414$, $v_{th\perp}/\mathrm{c} = 1$, $v_\perp/\mathrm{c} = 0.1$, $\frac{v_{ob}}{\mathrm{c}} = 0.5, 0.6, 0.7, 0.8, 0.9$ and $k \approx k_\perp$, $k_\perp \approx 100k_\parallel$.

The Graphical profile shows initially the growth rate is negligible up to $b \approx 1.546$ but rapidly increasing and attains maximum value at $b \approx 1.743$ and further increasing the value of b, the growth rate decreasing steeply up to $b \approx 6$ and showing the negligible value beyond $b > 6$. On the other view, it has seen that on decreasing the value of varying $\frac{v_{0b}}{c}$ as 0.5 to 0.9, the normalized growth rate is much increasing. As we see that strong growth rate $0.000597\omega_c$, $0.00818\omega_c$, $0.0097\omega_c$, $0.0109\omega_c$, $0.0117\omega_c$ are observed in fig.1. This promises that electrons can be accelerated by excited electron Bernstein wave very efficiently through the cyclotron damping. On comparing EBW taking consideration of relativistic case with normal extraordinary wave, one can estimate that relativistic factor much affects the growth rate. However beam has taken with finite extent. The excitation of Bernstein wave is determined by large $k_\perp$ and since here we assumed $k_y \gg k_x$, hence k_x does not play any significant roll on this system. The localization of EBW wave demonstrated as $\beta^{1/4}x = \zeta$ by which we analyzed that order of width is $\sim\beta^{-1/4}$. This width parameter depends on density scale length plasma as $R^{1/2}$ as given by equation (14b. By these parameters, growth rate can be controlled and it much decreases due the effect of non locality. In general analysis, we have stabilized a news theory of EBW excitation by a relativistic electron beam with loss cone velocity in magnetized plasma. The loss cone velocity consideration affected this mechanism while earlier works have done by other considerations. This theory governed that the presented excitation mechanism may be applicable in the heating of spherical torus, electron cyclotron heating.

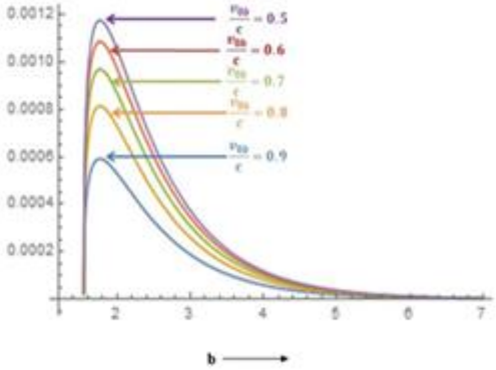

Figure 1: Variation of normalized growth rate $\frac{\gamma}{\omega_c}$ with b for $\omega_p/\omega_c = 1$, $\omega_{pb}/\omega_c = 0.1414$, $v_{th\perp}/c = 1$, $v_\perp/c = 0.1$, $\frac{v_{0b}}{c} = 0.5, 0.6, 0.7, 0.8, 0.9$ and $k \approx k_\perp$, $k_\perp \approx 100k_\parallel$.

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