Particle Acceleration due to Electrostatic Shock wave driven by Counterstreaming Pair Plasmas

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Abstract

By using particle-in-cell code, we investigated the particle acceleration due to electrostatic shock wave driven by counterstreaming instability in pair plasma with background magnetic field parallel to the direction of counterstreaming. We found the high-energy particle acceleration due to the electrostatic field parallel to the background magnetic field. The generation of electromagnetic fluctuations is restrained by strong background magnetic field, and consequently the electrostatic mode becomes dominat. Then, high-energy particles are produced from electrostatic field. This acceleration is more effective than the condition without background magnetic field.

1. Introduction

The studies of the interactions of plasma flows in collision-less plasma are important for a broad variety of problems ranging from laboratory plasmas to astrophysical plasmas. Even if there is charge neutrality and no magnetic field, the plasma flows generate the intense electric and magnetic field. This is referred to as counterstreaming instability that has the similar process to Weibel instability with anisotropic temperature [5]. Califano et al. [2] investigated, both analytically and numerically, electron-electron counterstreaming instability in electron-ion plasma by using both two-fluid equations and Maxwell equations. They derived the theoretical dispersion relation, and applied it to beam-plasma instability in laser plasma. Kazimura et al. [4] investigated electron-positron counterstreaming instability by using both linear theory and particle-in-cell simulation. They derived the dispersion relation from four-fluid equations with Maxwell equations, and compared the results derived from linear theory with the results of simulation. They noticed the linear stage of counterstreaming instability. In recently, Haruki et al. [3] investigated the non-linear stage of counterstreaming instability in pair plasma. They also derived the theoretical dispersion relation by using four-fluid equations with Maxwell equations, and compared the growth rate derived from the dispersion relation with that of simulation result. Further, in non-linear stage, they showed the generation of electrostatic shock waves which is caused by elec-

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Table 1. The parameters associated with the background magnetic field

Parameter	ω_{ce}/ω_{pe}	β	r_L	V_A
case1	0	-	-	-
case2	0.5	0.08	2.0Δ	0.3c
case3	1.0	0.02	1.0Δ	0.6c
case4	1.5	0.009	0.66Δ	0.72c
case5	1.7	0.006	0.57Δ	0.76c
case6	2.0	0.005	0.5Δ	0.8c

trostatic counterstreaming instability. The generated electrostatic waves create some high energy particles.

Previous papers that related to counterstreaming instability have not discussed about the effects of background magnetic field, B_0. Here we had a question, what happens when counterstreaming instability occurs in the magnetic field? To answer this question, in this paper, we investigated the counterstreaming instability in pair plasma, with background magnetic field parallel to the direction of counterstreaming, by using particle-in-cell code.

2. Simulation model

We used two-dimensional, fully electromagnetic, and relativistic particle-in-cell code [1]. The lengths of system are $L_x = 4000\Delta$ and $L_y = 64\Delta$, where Δ is grid size. The periodic boundary conditions are imposed in both x and y direction. There is 60 electron-positron pairs in a cell uniformly in whole system. The background magnetic field and counter velocity are parallel, have used their direction to define the x-axis. To set the counterstreaming plasma, we divided all particles into two components. Both electrons and positrons in the left hand side have the velocity, 0.5c, and in the right hand side have the velocity, -0.5c. The other parameters are as follows: the simulation time step is $\omega_{pe}t = 0.05$, where ω_{pe} is electron plasma frequency; the Debye length and skin depth are 1Δ and 10Δ, respectively; the both electron and positron thermal velocity are 0.1c. The parameters associated with the background magnetic field are listed in Table 1.

3. Simulation Results

The both electric field and magnetic field are generated by counterstreaming instability, which is similar process to Weibel instability. Figure 1. shows the electric field E_x and magnetic field B_z configurations at $\omega_{pe}t = 25.0$, which are generated by this instability. The schematic picture in Fig.1. shows the whole system of this simulation. We plotted the magnetic field and electric field on the

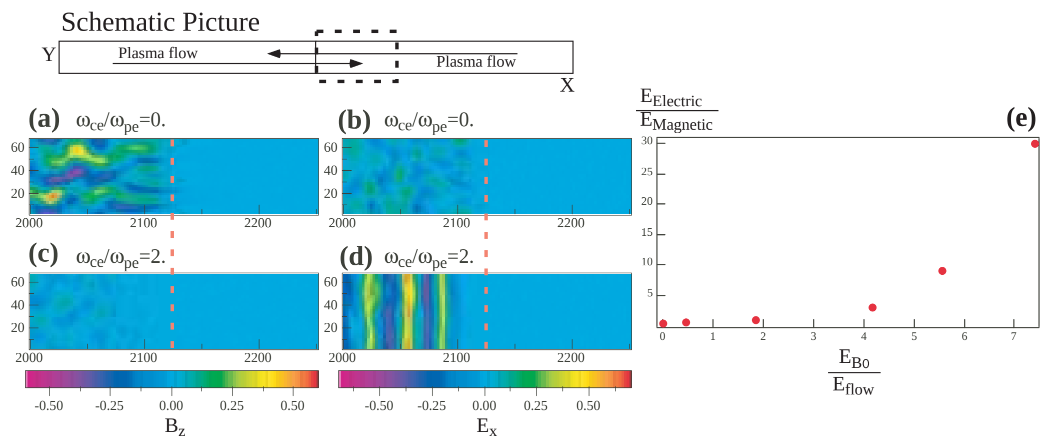

Fig. 1. The schematic picture shows the whole system of this simulation. The dashed square indicates the plotting region for (a), (b), (c), and (d). (a) and (b) show B_z and E_x configuration without magnetic field case, (c) and (d) show them with $\omega_{ce}/\omega_{pe} = 2$ at $\omega_{pe}t = 25.0$. The red dashed line indicates the front of plasma flow. (e) shows the ratio of generated electric field and magnetic field energy.

region surrounded by dashed square of the schematic picture. Fig.1. (a) and (b) show B_z and E_x configuration without the background magnetic field, (c) and (d) show them with $\omega_{ce}/\omega_{pe} = 2.$. The dashed red lines on (a), (b), (c) and (d) show the front of the plasma flow. When ω_{ce}/ω_{pe} becomes large, the generation of magnetic field is restrained by the background magnetic field, while the electric field becomes strong, and becomes longitudinal wave from transverse wave. This means that the wave generated by counterstreaming instability is changed to the electrostatic mode from electromagnetic mode by the strong background magnetic field. Fig.1.(e) shows the ratio of the generated electric field energy $E_{Electric}$ and the magnetic field energy $E_{Magnetic}$ at linear stage. The horizontal axis shows the ratio of background magnetic field energy E_{B_0} and plasma flow energy E_{Flow}. The ratio of $E_{Electric}$ and $E_{Magnetic}$ suddenly increase when the ratio of E_{B_0} and E_{Flow} exceeds 3 or 4. This means that the generation of electric field is superior than the generation of magnetic field, which indicates that the nature of generated wave becomes electrostatic mode from electromagnetic mode.

The generated wave accelerates the some particles. Fig.2. shows the electron velocity distribution in x direction parallel to the both magnetic field and counterstreaming. The red, green, and blue lines indicate the velocity distribution at the initial, $\omega_{pe}t = 200$ without background magnetic field, and $\omega_{pe}t = 200$ with $\omega_{ce}/\omega_{pe} = 2$, respectively. Here, v_x is normalized by light velocity. In the condition $\omega_{ce}/\omega_{pe} = 2.$, the electrostatic field can more effectively accelerate the electrons to the x direction than the electromagnetic wave driven by the instability without the background magnetic field. In this condition, the maximum Lorenz gamma

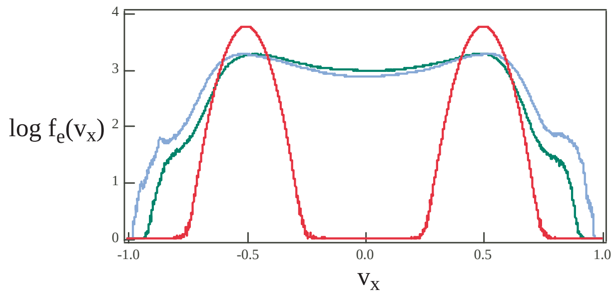

Fig. 2. The red, green, and blue lines show the electron velocity distribution in x direction of $\omega_{pe}t = 0.$, $\omega_{pe}t = 200.$ without B_0, and $\omega_{pe}t = 200.$ with $\omega_{ce}/\omega_{pe} = 2.$, respectively. v_x is normalized by light velocity.

of electron is about 3, and the number of accelerated particles that exceeds $0.9c$ is about two hundreds times as the number of accelerated particles in the condition without background magnetic field. The positron velocity distributions are the almost same as the electron velocity distributions.

4. Conclusions

We investigated the particle acceleration due to electrostatic shock wave driven by counterstreaming pair plasmas with background magnetic field parallel to the counterstreaming direction. The background magnetic field restrains the generation of electromagnetic wave driven by this instability, and consequently it generates the electrostatic wave that has the wave vector parallel to the both magnetic field and counterstreaming. This means that the nature of countersteraming instability becomes electrostatic mode from electromagnetic mode. This electrostatic field effectively accelerates the particles to the direction parallel to the both magnetic field and counterstreaming.

5. References

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