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Magnetic Field Generation during the Collision of Counter Streaming Flows

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Abstract

We investigate the collision of electron-ion plasma clouds by using 2D3V fully relativistic electromagnetic PIC code. We find that the magnetic field is produced in the perpendicular direction to the plasma streams. The results obtained here may be applicable to the laser-plasmas.

Keywords:
magnetic field generation, laser-plasmas, diocotron instability, weibel instability, inverse cascade

1. Introduction

We present results of 2D3V PIC simulations of electron-ion plasma clouds collision, which are obtained by modifying the *3D3V* TRISTAN code (Buneman [1]). In our recent papers [2,3], we investigated that a quasi-static magnetic field can be generated associated with the counter-streaming instability. In that simulation, we found that the magnetic field is produced in the direction perpendicular to streams and it develops to a large scale structure in the nonlinear stage.

In the present paper, we investigate the collision dynamics of counter-streamings with cylindrical configuration. We found that there occur two different kinds of instabilities: one looks like the Weibel [4] instability that occurs in a plasma with anisotropic temperature, the other is the Diocotron instability. When the velocity, electric field, and magnetic field are mutually perpendicular, the unstable mode is known as the Diocotron instability. As an application like this plasma, we mention the plasma around fuel pellet carrying out the direct drive implosion, which is the heating method of the fusion material. In the plasma, some particles can be accelerated by laser pulse irradiating to the fusion material. Company with the particle acceleration, a current which direction is opposite to the propagation of laser can be produced. So the particles in the plasma interacts with the laser pulse, and cause some instabilities. In this kind of interaction process, it is essential to consider the relativistic effect owing to the relativistic electron acceleration.

2. Simulation Model

The system size used in the simulation is $L_x = 256\Delta$ and $L_y = 256\Delta$. Periodic boundary conditions on the fields and particles are used in both x and y directions. The particle number density is about 20 particles per cell. $\Delta = 1.0$ is a grid size.

The ions are assumed to be at rest. Initially the electrons have two counter-streaming components with different velocities and densities. We give the electron velocity distribution as shifted Maxwellian with $v_{1e} = 0.3c$ and $v_{2e} = -0.6c$ in the z-direction and each density is $n_{1e} = 2n_{0e}/3$ and $n_{2e} = n_{0e}/3$, where the condition $\sum n_{ea}v_{ea} = 0$ is satisfied. c is the light velocity and n_{0e} is the initial electron number density. Those particles are

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distributed with cylindrical configuration in the center of the system. The radius of cylindrical configuration is 64Δ. The other parameters are as follows: the mass ratio $m_i/m_e = 64$, $\omega_{pe}\Delta t = 0.05$, where Δt is the integration time step, the electron collision-less skin depth is $d_e = c/\omega_{pe} = 9\Delta$.

3. Simulation Results

The main result is the generation of magnetic fields B_x and B_y perpendicular to the stream direction. We study the structure of the electric currents in the nonlinear stage which are associated with the quasi-static magnetic field. The electric fields E_x and E_y also appear in the perpendicular direction to the initial flow owing to the instability. The electrons which have a drift velocity in z-direction are accelerated or decelerate by the electric field produced in x-y plane. So we think that the formation of electric current J_z from the current-less stream is the result of interaction between charged particles and laser pulse.

At first Fig. 1 shows the development of current J_z which is obtained from the rotation of generated magnetic fields B_x and B_y. Initially, there appear structures which characteristic scale is about the electron skin depth. This instability corresponds to the Weibel-type instability, which is investigated in the literatures [3,5]. The thermal velocity in all directions are the same. But we set a drift velocity in z-direction, so there is the anisotropy between the z-direction and other directions. Therefore we called it Weibel-type instability. The structures which scale are electron skin depth appear by Weibel-type instability. But in the nonlinear stage, the electric current structure becomes large scale as time goes on owing to $\boldsymbol{J} \times \boldsymbol{B}$ force of the current filaments with the same current directions.

Figure 2 shows the vector plots of the electric fields E_x and E_y in the x-y plane. We find that the electric field appears in perpendicular direction to the magnetic field, by comparing the magnetic field vectors in Fig. 1-c and the electric field vectors, in Fig. 2 at the same points in

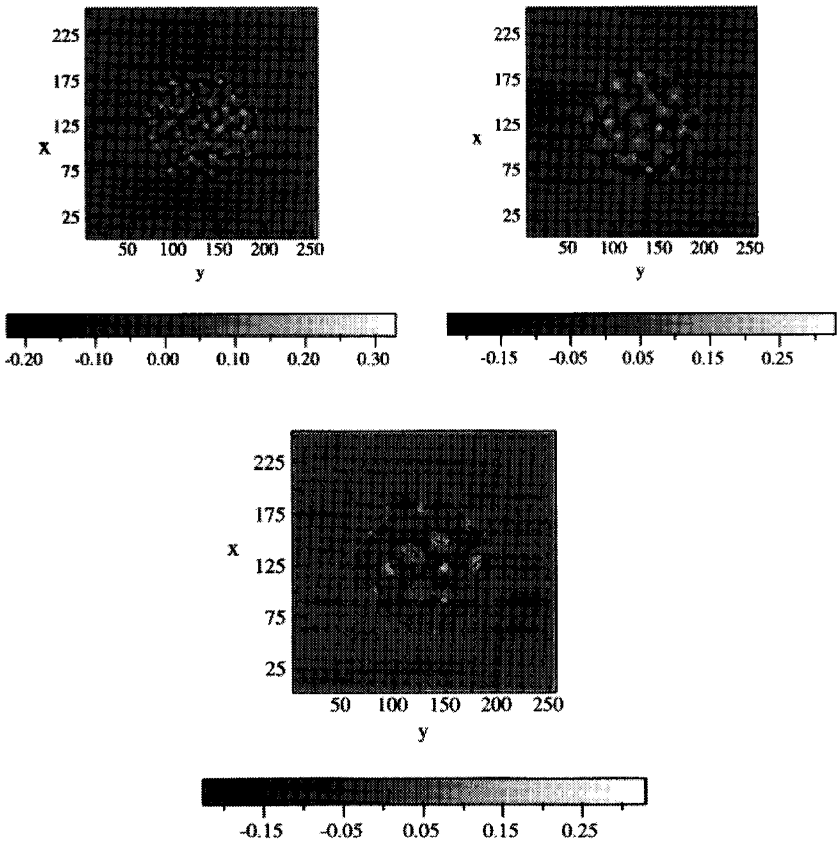

Fig. 1 Time development of current (Jz) structures in the $x-y$ plane: (a) $\omega_{pe}t = 10$, (b) $\omega_{pe}t = 20$, and (c) $\omega_{pe}t = 50$, with $B_x - B_y$ vector plots.

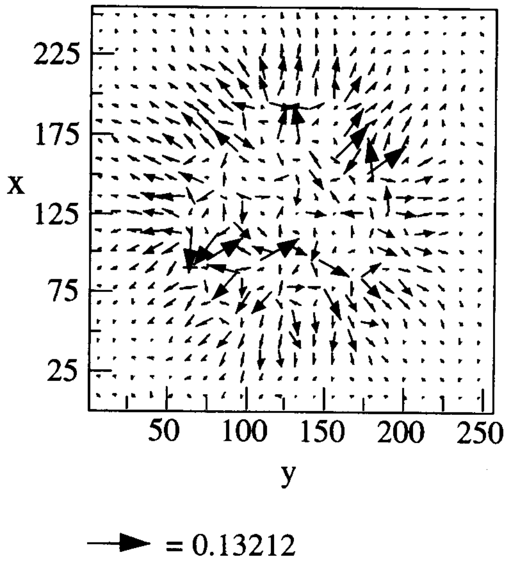

Fig. 2 The vector plots of electric field $E_x - E_y$ at $\omega_{pe}t$ = 50.

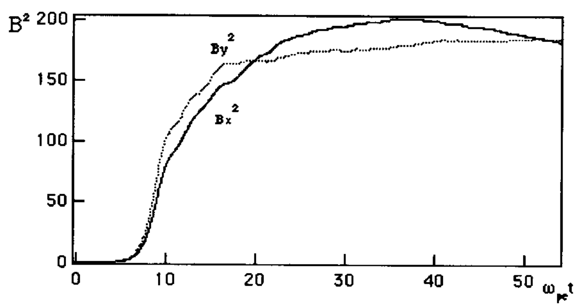

Fig. 3 The time history of magnetic field energy in the direction perpendicular to the streams.

the plane. We also find that the direction of these vectors is perpendicular to the stream velocity. The characteristics that the velocity, electric field, and magnetic field are mutually perpendicular, is known as the Diocotron instability. Fig. 3 shows the time history of magnetic field energy in the direction perpendicular to the streams. The structure of the magnetic field also develops to a large scale as well as the current structure.

By using the final value of magnetic field energy, we can estimate the energy conversion rate from the initial flow energy. We find that the energy conversion rate is about 20%. The other energy almost converted to electron and ion energy. Fig. 4 and Fig. 5 show the structure of density distribution and charge density at the final time, respectively. The structure of density distribution is very similar to the structure of charge density. It is also characteristics of the Diocotron instability. On the other hand, the structure of density distribution is different from the current structure, as seen Fig. 1-c.

In order to study the energy flow in the wave number space, we performed a 2-D Fourier transformation of current J_z in the x and y direction. As shown in Fig. 6, there occurs the energy flow from large wave-number to small wave number region, which is called as the "Inverse cascade" process. That is to say, it means that the structure of current J_z becomes larger.

4. Summary

We present results of 2D3V PIC simulations of electron-ion plasma clouds collision. There occur two different instabilities: one is the Weibel-type instability

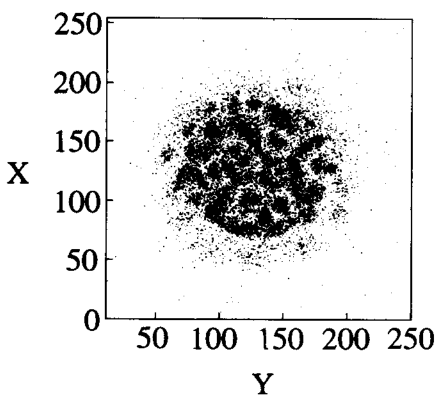

Fig. 4 The electron density distribution at $\omega_{pe}t = 50$.

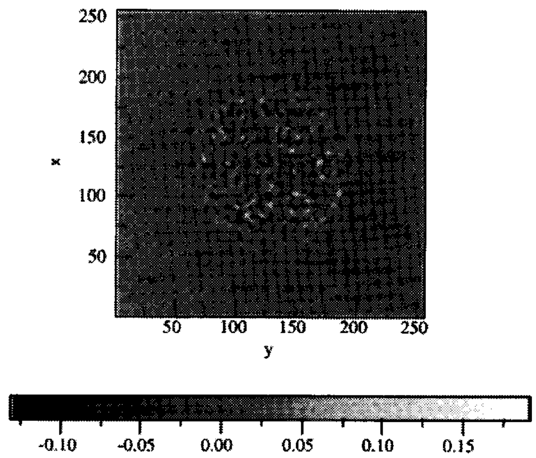

Fig. 5 The structure of charge density at $\omega_{pe}t = 50$.

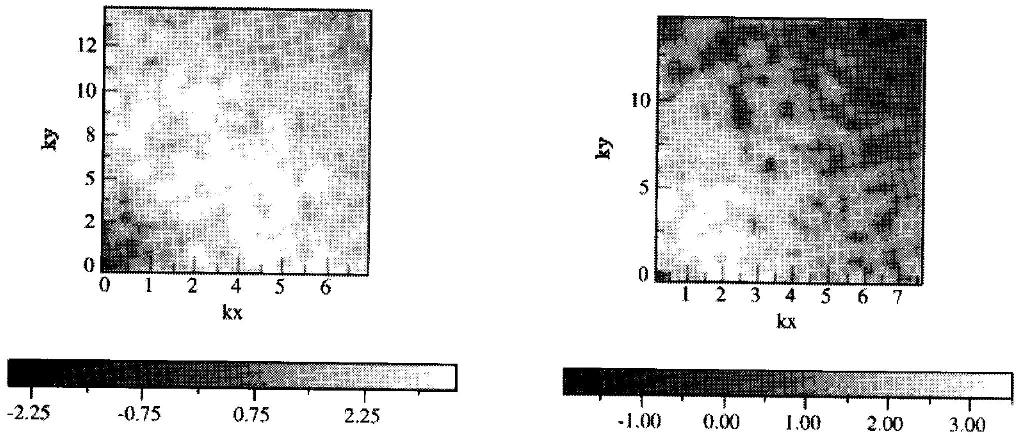

Fig. 6 Intensity of J_z as a function of k_x and k_y: (a) $\omega_{pe}t$ = 10, (b) $\omega_{pe}t$ = 50.

and the other is the Diocotron instability, which is characterized that flow velocity, electric field, and magnetic field are mutually perpendicular. The most important result is the generation of magnetic fields in the direction perpendicular to streams and its structure develops to a large scale. These processes may be important for understanding magnetic field generation in plasmas interacting with strong laser pulses.

Acknowledgment

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