ELECTORON ACCELERATION IN A SYSTEM OF INVERSE SYCHROTRON RADIATION

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Abstract

It is found that an electron can be efficiently accelerated by a simple system which is composed of a pulse plane electromagnetic wave and a static magnetic field. The single particle analyses and the simulation show that the system works well for a high-energy electron acceleration and agree with analytical results.

## Introduction

Recently, a number of mechanisms[1-19] have been proposed for high-enagy particle acceleration. First we present a new mechanism for high-energy electron acceleration by a pulse plane electromagnetic (EM) wave propagating with a light speed (c). In this mechanism an EM wave traveling across a weak static magnetic field can accelerate electrons. Second, the optimal magnitude of static magnetic field is discussed.

## Acceleration mechanism

Figure 1 shows the proposed mechanism for high-energy electron acceleration by an EM wave with a static magnetic field. A plane EM wave propagates with a light speed (c) in the +x direction. The magnetic component of the wave in the x-z plane($B_z$) and the electric one is in the x-y plane($E_y$). An electron speed is less than c. Therefore the EM wave propagating with c catches up with the electron and leaves it behind. Let us consider a case with no static magnetic field. After an EM wave passes through an electron by the half wavelength, the electron can absorb the wave energy. But in the rest half wavelength the electron looses its energy. As a result, the electron cannot absorb the EM wave energy. This fact comes from the symmetry of the EM wave in space. Our new idea is to remove this symmetry by applying a static magnetic field($B_{app}$). Therefore the applied static magnetic field has an important roll for this mechanism shown in Fig. 1.

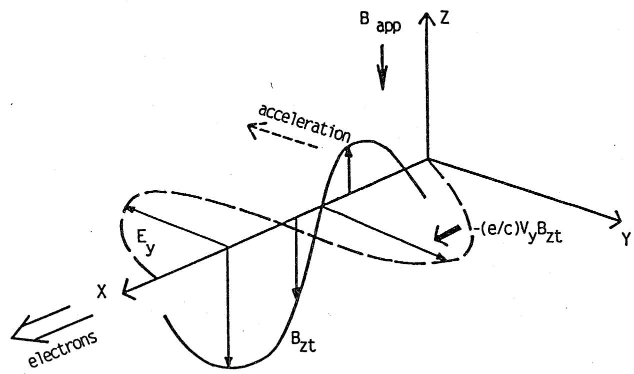


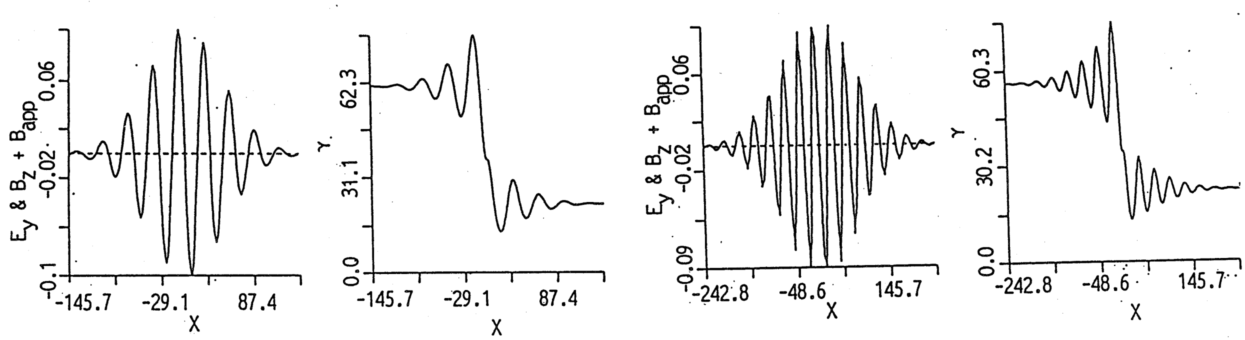

Fig.1 A mechanism of the electron acceleration of inverse synchrotron radiation .

## Numerical single particle analyses

We employed the Gaussian pulse plane EM wave. The pulse is

$$Ey=Bz=-A\exp[(x-ct)^2/2M^2]\sin[k(x-ct)] \qquad (1)$$

Here M determines the length of pulse and A is the amplitude of the EM wave. Figure 2(a) shows this Gaussian pulse. In this example M=3L/2, A=1.64x10$^6$/L volt/cm =0.1x$E_0$, L is the wavelength in cm. First we performed a single particle analysis in a fixed field presented in Eq.(1). In this analysis, the electron is in front of the pulse plane EM wave in the initial




(a) M=3L/2 and the initial velocity $v_0$=0.999c (b) M=5L/2 and the initial velocity $v_0$=0.999c

Fig.2. The gaussian pulse plane EM wave and the trajectory of the relativistic factor versus x in the wave coordinate. In the main one wavelendth of the pulse the electron absorbed the wave energy. In this figure the EM wave propagates in the +x direction, the initial position of the electron is the right end of this figure and the electron moves to the left end of this figure.

time. Figure 2 also shows the results of this analysis.

### Simple analyses

The equation of motion and energy equation are as follows:

$$dP_x/dt=-ev_y(B_z+B_{app})/c, \quad (2)$$
$$dP_y/dt=F_y=-e[(1-v_x/c)B_z-v_xB_{app}/c] \quad (3)$$
$$d(mc^2\gamma)/dt=-eE_yv_y \quad (4)$$

Here $\beta_x=v_x/c$, $\beta_y=v_y/c$, $E_y=B_z=A\sin[k(x-ct)]$. From the energy equation it is clear that $v_y$ is important to accelerate the electron, because $E_y$ is specified by the incoming EM wave. The $v_y$ is determined by Eq.(3). The force in the y direction is proportional to the factor of $(1-\beta_x)B_z-{}_xB_{app}$. Here we assume that the electron moves with $v_0$ in +x direction at the initial time. The initial electron velocity $v_y$ is zero. By the Lorentz transformation of Eqs.(2), (3) and (4) into a frame moving with the particle inital velocity $v_0$ in the +x direction, and also assuming that the particle location of x direction is zero at the initial time and $v_x$ is zero in the moving frame, we obtain the optimal $B_{app}$ for the optimal acceleration:

$$B_{app} = -2(1-\beta_x)A/\pi\beta_x \quad (5)$$

By using Eqs.(3), (4) and (5), we obtain final $\gamma$, that is,

$$\gamma = \gamma_0[1+(2qA\lambda/\pi mc^2)^2]^{1/2} \quad .(6)$$

Figure 3 shows final $\gamma$ versus the electron initial speed obtained by the single particle analyses and by simple analysis, and presents the good agreement between them.

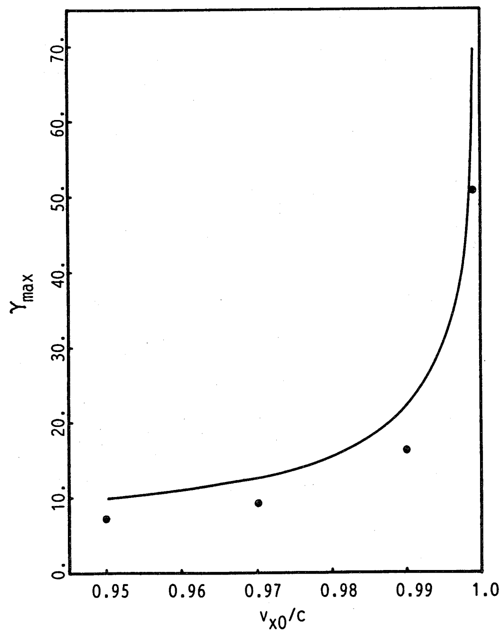
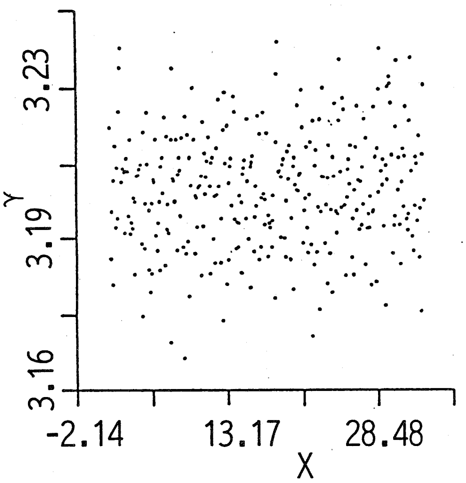
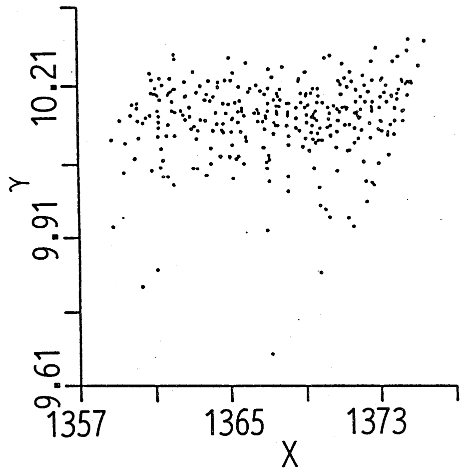



Fig.3 The final $\gamma$ versus the initial electron speed. A solid line shows the results by single particle analyses and dots show results estimated by simple analyses(Eq.(6)).




(a) The initial




(b) The final

Fig.4 Particle simulation result for high energy electron acceleration by the pulse plane EM wave. The relativistic factor versus x. Figyre (a) shows the initial and (b) shows the final.

## Particle simulation

We also performed the 1.5-dimensional( x, $v_x$ and $v_y$ ) particle-in-cell(PIC) simulation. The relativistic equation of motion and Maxwell equation are solved in the program self-consistently. Figure4 shows a simulation result for $\gamma$ versus x. The employed parameters in this simulation are as follows: the initial electron velocity $v_0$=0.95c, the electron number density $n=1.26\times10^9 P/L^2\ cm^{-3}$, the electron temperature 100 eV, the amplitude of the pulse plane EM wave $A=0.1\times E_0$, M=L/2 and $B_{appp}=-0.0549\times A$. In Fig.4 electrons are accelerated well and the final $\gamma$ agrees with results by numerical analyses and by simple analyses.

## Conclusions

In this paper, we proposed a new mechanism for high energy electron acceleration by a pulse plane EM wave traveling across a weak static magnetic field, and demonstrated its viability and effectiveness by numerical analyses and particle simulation.

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