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EFFECT OF CHIRPED PULSE ON ELECTRON ACCELERATION IN THE INVERSE FREE-ELECTRON LASER

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Abstract. Electron acceleration by a chirped laser pulse is studied numerically in the presence of helical magnetic wiggler in vacuum. The type of chirp is linear and positive. It is shown *that for* specific value of chirp parameter, inverse free-electron resonance condition can be maintained for longer duration and electron can gain much higher energy. It is shown that chirp *parameter, the* initial phase of laser and laser intensity have a strong influence on the electron acceleration.

Keywords: Chirp, Electron acceleration, Free- electron laser

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1. INTRODUCTION

Recent developments in laser technology provide the possibility for fulfillment of experimental tests about electron acceleration designs with laser (Singh, 2004) (Bingham, Mendonca, & Shukla, 2004). The interaction of inverse free-electron laser (IFEL) as a laser acceleration process in the vacuum was suggested in 1970 with a high acceleration Gradient (Palmer, 1972) (Courant, Pellegrine & Zakowicz, 1985). Producing the first inverse free-electron laser, the first experimental work was begun at Colombia University in 1990 (Wernick & Marchal, 1992), and it was continued using laser pulse CO_2, power around GW and nanosecond pulse durability in Brookhaven National Laboratory (Van Steenbergen, Sandweiss, & Fang, 1996).

2.ELECTRON DYNAMICS

In the inverse free-electron laser, the snip of electron and laser beam is diffused in the magnetic field, called wiggler, in the vacuum space. Wiggler results in a frequency in the electron path in a transverse direction. In case the magnetic field of the laser pulse involves a component in the direction of the electron, due to the sign of the laser pulse magnetic field (the relative phase of the electron), the field can accelerate the electron or be accelerated by that. In order to obtain and exchange the energy during the wiggler, the resonance condition (Marshal, 1985) (Roberson& Sprangle, 1989) in the free-electron laser $\gamma^2 = (1+K^2)\lambda_w/2\lambda_l$ should be satisfied, where λ_l, λ_w, $K = eB_w k_w/2\pi mc$ are the laser wavelength, wiggler wavelength, and wiggler parameter, respectively. B_w, m, c are the magnetic wiggler amplitude, electron mass and the speed of light, respectively.

One of the main constraints of this acceleration scheme is the dephasing of the electron compared to the laser pulse. the resonance condition of the free-electron laser cannot be maintained for a long time if the energy of the electron increases. This problem can be solved in two different ways: the duration and (or) the amplitude of the magnetic field slowly changes (Singhand & Tripathi, 2004) (Moore, 1988), or that the laser pulse would be used with a variable frequency (Hartemann, Landahl, Troha, et al., 1999). In this paper, the interaction between electron and a chirped laser pulse in the presence of Wiggler was studied numerically and it was showed that the chirped laser pulse results in the preservation of the resonance condition for a longer period of time, indicating the fact that electron energy can be effectively changed before phase disappears in the interaction.

There are various ways to produce chirped pulses, including using solid-state laser systems and free-electron laser oscillators, electromagnetic pulses reflected from the front side of the relativity ionized air and pulse propagation through the plasma channel, to name a few (Khachatryan, Van Goor & Boller, 2004) (Khachatryan, Van Goor, Verchuur & Voller, 2005) (Gordon, Hafizi, Hubbard, Penano, Sprangle & Ting, 2003) (Hajima, & Nagai, 2003).

In this study, the equations of relativity motion of a single electron are numerically stimulated using fourth order Runge-Kutta method.

3.MATHEMATICS EQUATIONS

Given laser pulse with circular polarization is released alongside $\hat{z}$. The components of the magnetic field of the pulse laser are expressed as follows:

$$E_x = E_0 \cos(\omega(\zeta) + \varphi_0) f(z - ct) \quad (1)$$

$$E_y = E_0 \sin(\omega(\zeta) + \varphi_0) f(z - ct) \quad (2)$$

Where E_0 is the magnetic field amplitude, φ_0 the initial phase of the field, $\omega(\zeta) = \omega_0 + b\zeta$ momentary frequency, $\zeta = z/c - t$ reparded time, b chirped parameter, and ω_0 the frequency in $\zeta = 0$.

Gaussian for laser pulse is given as follows:

$$f(z - ct) = exp\left[-\frac{\left((z - z_{0p}) - ct\right)^2}{\sigma_p^2}\right] \quad (3)$$

Where z_{0p} is the initial location of the laser pulse peak and σ_p the laser pulse length.

The components of the magnetic fields of the laser pulse were obtained using Maxwell's equations.

$$\vec{\nabla} \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} \quad (4)$$

One-dimensional Wiggler is given as:

$$\vec{B}_w = B_w(\hat{x}\cos(k_w z) - \hat{y}\sin(k_w z)) \quad (5)$$

Where B_w is the amplitude and k_w the magnetic Wiggler wave number.

To study dynamic of electron motion in these fields, a three-dimensional simulation is constructed for a particle by using relativistic equation of Newton-Lorentz.

$$\frac{d}{dt}(\gamma m_0 \vec{v}) = -e\left(\vec{E} + \frac{\vec{v} \times \vec{B}}{c}\right) \qquad (6)$$

m_0, e, v are the mass of rest, electron charge, and electron velocity respectively. $\vec{E}$ is the Laser pulse electric field and $\vec{B} = \vec{B}_w + \vec{B}_l$ where $\vec{B}_w$ is the Wiggler magnetic field and $\vec{B}_l$ is the magnetic field produced by the laser pulse.

In this study, the followings became dimensionless: the quantities x, y, z, σ_p with the laser wave number, the electric and magnetic fields with $e/m_0 c\omega_0$, and t with ω_0. The following dimensionless variables are used in the equations.

$$\frac{eE_0}{m_0 c\omega_0} \rightarrow a, \qquad \frac{eB}{m_0 c\omega_0} \rightarrow b, \qquad \frac{v_i}{c} \rightarrow \beta_i$$

$$\frac{p_i}{m_0 c} \rightarrow p_i, \qquad \omega_0 \zeta \rightarrow \xi, \qquad \frac{b}{\omega_0^2} \rightarrow \acute{b}$$

Using these variables, dimensionless equations of motion become as follows.

$$\frac{d\beta_x}{d\tau} = \frac{1}{\gamma}\left[a_x(\beta_x^2 - 1) - \beta_z b_y + a_y \beta_x \beta_y\right] \qquad (7)$$

$$\frac{d\beta_y}{d\tau} = \frac{1}{\gamma}\left[a_y(\beta_y^2 - 1) - \beta_z b_x + a_x \beta_x \beta_y\right] \qquad (8)$$

$$\frac{d\beta_z}{d\tau} = \frac{1}{\gamma}\left[\beta_y b_x - \beta_x b_y + \beta_z(a_x \beta_x + a_y \beta_y)\right] \qquad (9)$$

And the energy changes would be written as follows.

$$\frac{d\gamma}{d\tau} = -(a_x \beta_x + a_y \beta_y) \qquad (10)$$

The equations were solved by fourth order Runge-Kutta method and in any energy desirable moment, the electron velocity and position was obtained.

4.NUMERICAL RESULTS

In this section, we will examine the stimulation results of the interaction between electron and chirped laser pulse in the presence of the magnetic wiggler.

Here, the laser pulse CO_2 with the peak intensity about $3.05 \times 10^{15}\, W/cm^2$, the wavelength $\lambda_l = 10.6\mu m$ and the pulse duration $t_p = 5Ps$ were used. Dimensionless parameters for the laser pulse involve the characteristics $\tau_p = 1000$ and $a = 0.5$. The amplitude of wiggler field and its wavelength is $10KG$ and $\lambda_w = 0.477cm$ respectively. The primary given conditions is that in the moment $t = 0$ the initial location of electron is in $(x_0, y_0, z_0) = (0,0,1700)$ and the peak location of the laser pulse is in $z_{0p} = -\tau_p$. The electron primary energy is $\gamma_0 = 10$ and the transverse components of the electron velocity are also zero.

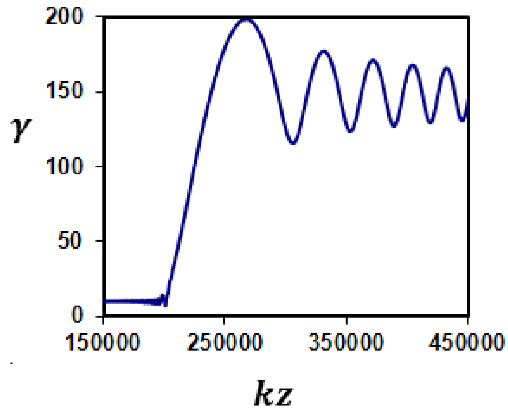

Figure 1: electron normalized energy in term of the normalized z coordinate

In figure 1, electron energy is plotted by location in which the chirped parameter is $\acute{b} = -0.002$.

The chirped parameter is optimized in the interval $(-0.1, -0.001)$; which for this optimal value, the phase between electron and laser pulse is preserved for a longer period of time and the electron gets much more energy from pulse.

In figure 2, electron energy is plotted by the chirped parameter which, as you can see, its optimal point is in -0.002.

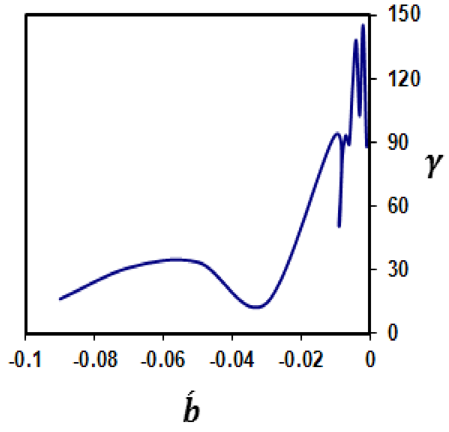

Figure 2: electron normalized energy in terms of the dimensionless chirped parameter

In figure 3, the electron final energy is plotted in terms of the initial phase of the laser. It is observed that the electron final energy is very sensitive to the relative phase of the laser pulse, because, due to the electric field phase of the laser pulse toward the electron, it is possible for the laser pulse to get energy from electron and then, anti-acceleration or laser process would happen.

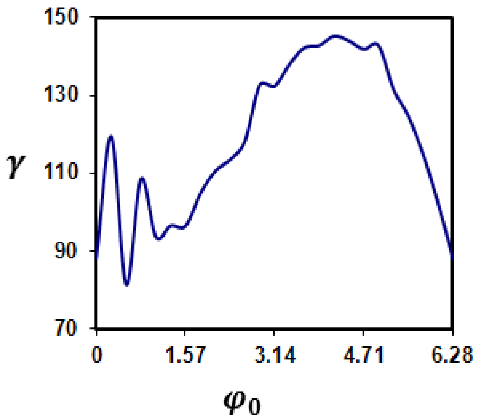

Figure 3: the electron energy in terms of the initial phase of the field

In figure 4, the electron final energy is plotted in terms of the laser pulse. It is observed that by increasing the intensity of the laser pulse, electrons with higher energies can be achieved.

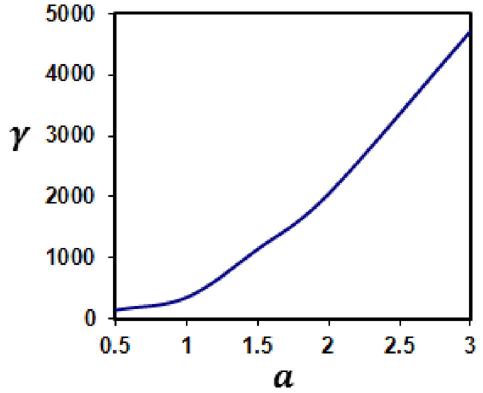

Figure 4: the electron normalized energy in terms of the intensity of the laser pulse

5. CONCLUSION

Due to the acceleration condition in the free-electron laser, the increased electron energy during interaction with the laser pulse causes phase conditions to meet between electron and pulse for a short period of time. Therefore, the phase conditions, with a chirped pulse, maintains for a longer time and as a result of that, electron gain energy is considerable.

REFERENCES

Bingham, R., Mendonca, J. T. & Shukla, P. K. (2004). *Plasma Phys. Controlled Fusion 46*, Rl

Courant, E. D., Pellegrine, C., & Zakowicz, W. (1985). *Phys. Rev. A* 32, 2813.

Gordon, D. F., Hafizi, B., Hubbard, R. F., Penano, J. R., Sprangle, P. & Ting, A. (2003). *Phys. Rev. Lett.* 90, 21500

Hajima, R. & Nagai, R. (2003). *Phys. Rev. Lett*. 91, 024801

Hartemann, F. V., Landahl, E. C., Troha, A. L. et al. (1999). *Phys. Plasmas* 6, 4104

Khachatryan, A. G., Van Goor, F. A. & Boller, K. J. (2004) *Phys. Rev. E* 70, 067601;

Khachatryan, A. G., Van Goor, F. A., Verchuur, J. W. J. & Voller, K. J. (2005). *Phys. Plasmas* 12, 062116

Marshal, T. C. (1985) Free Electron Lasers (McMillan, New York.

Moore, G. T. (1988). *Phys. Rev. Lett*. 60, 1825

Palmer, R. B. (1972). *Appl. Phys.* 43, 3014

Roberson, C. W. & Sprangle, P. (1989). *Phys. Fluids B* 1, 3

Singh, K. P. (2004). *Phys. Plasmas.* 11, 1164

Singhand, K. P. & Tripathi, V. K. (2004). *Phy. Plasmas* 11, 743

Van Steenbergen, A., Sandweiss, J. & Fang, J. M. (1996). *Phys. Rev. Lett.* 77, 2690

Wernick, I. & Marchal, T. C. (1992). *Phys. Rev. A* 46, 3566