Publ. Astron. Obs. Belgrade No. 102 (2022), 187 - 190 *Contributed Paper*

LASER DRIVEN ELECTRON ACCELERATION BY q-GAUSSIAN LASER PULSE IN PLASMA: EFFECT OF SELF FOCUSING

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Abstract. A scheme for electron acceleration by self focused q-Gaussian laser pulses in under dense plasma has been presented. The relativistic increase in the mass of plasma electrons gives nonlinear response of plasma to the incident laser pulse resulting in its self focusing. Under the combined effects of saturation nature of relativistic nonlinearity of plasma, self focusing and diffraction broadening of the laser pulse, the beam width of the laser pulse evolves in an oscillatory manner. An electron initially on pulse axis and at the front of the self focused pulse, gains energy from it until the peak of the pulse reaches. When the electron reaches at the tail of the pulse, the pulse begins to diverge. Thus, the deacceleration of the electron from the trailing part of pulse is less compared to the acceleration provided by the ascending part of the pulse. Hence, the electron leaves the pulse with net energy gain. The differential equations for the motion of electron have been solved numerically by incorporating the effect of self focusing of the laser pulse

1. INTRODUCTION

Whenever we think of particle accelerators, we consider them to be meant only for research at the very edge of known physics as these enormous facilities take decades to build[1-3]. However, along with this lofty goal, though, particle accelerators are being used for decidedly more down-to-Earth projects-cancer treatments and medical sterilization, security screening, research into new materials, biological processes, and much more.

As plans are laid for the world's largest accelerator, the Superconducting Supercollider, accelerator technology is approaching" practical limits. There are two reasons. First, the forces from magnetic fields are becoming greater than the structural forces that hold a magnetic material together; the magnets that produce these fields would themselves be torn apart[10]. Second, the energy from electric fields is reaching the energies that bind electrons to atoms; it would tear electrons from nuclei in the accelerator's support structures. In this regard a new scheme of acceleration of charged particles by intense laser pulses propagating through plasmas, has gained a significant interest among researchers[4,5]. The aim of this paper is to give first theoretical investigation on laser driven electron acceleration on self focused q-Gaussian laser pulse in plasma..

2. SELF FOCUSING of LASER PULSE

Consider the propagation of a circularly polarized laser pulse with angular frequency ω_0 and wave number k_0 through a plasma with equilibrium electron density n_0. The electric filed vector of the laser pulse is given by

$$\boldsymbol{E} = A_0\, e^{\iota(k_0 z - \omega_0 t)} e^{-\frac{\left(\frac{t-z)}{v_G}\right)^2}{2\tau_0^2}} (\boldsymbol{e_x} + \iota \mathbf{e_y}) \tag{1}$$

where, v_G is the group velocity of laser pulse and τ_0 is its pulse duration. The dielectric function of plasma can be written as

$$\epsilon = 1 - \frac{\omega_p^2}{\omega_0^2}$$

where,

$$\omega_p^2 = \frac{4\pi e^2}{m_e} n_0 \tag{2}$$

is the equilibrium plasma frequency, (m_e, e) being the electronic mass and charge respectively. Under the intense field of the laser pulse the oscillations of the plasma electrons become relativistic and the mass m_e of the electron in eq.(2) need to be replaced by the relativistic mass, which is related to pulse amplitude as[26]

$$m_e = m_0 \sqrt{1 + \frac{e^2}{m_0^2 c^2 \omega_0^2} A_0 A_0^\star} \tag{3}$$

Thus, in the presence of laser pulse the dielectric function of plasma gets modified as

$$\epsilon = 1 - \frac{\omega_{p0}^2}{\omega_0^2} \left(1 + \frac{e^2}{m_0^2 c^2 \omega_0^2} A_0 A_0^\star\right)^{-\frac{1}{2}} \tag{4}$$

where,

$$\omega_{p0}^2 = \frac{4\pi e^2}{m_0} n_0$$

is the equilibrium plasma frequency. Thus, the relativistic effects make the index of refraction of plasma intensity dependent which in turn due to the spatial dependence of the amplitude structure of the laser pulse, resembles to that of graded index fiber. Separating the dielectric function of plasma into linear (ϵ_0) and nonlinear (ϕ) parts as

$$\epsilon = \epsilon_0 + \phi(EE^\star)$$

we get

$$\epsilon_0 = 1 - \frac{\omega_{p0}^2}{\omega_0^2} \tag{6}$$

and

$$\phi(EE^\star) = \frac{\omega_{p0}^2}{\omega_0^2} \left\{ 1 - \frac{1}{\left(1 + \frac{e^2}{m_0^2 c^2 \omega_0^2} A_0 A_0^\star\right)^{\frac{1}{2}}} \right\} \tag{7}$$

Now, the wave equation governing the evolution of amplitude A_0 of the laser pulse is

$$\iota\frac{\partial A_0}{\partial z} = \frac{1}{2k_0}\nabla_\perp^2 A_0 + \frac{k_0}{2\epsilon_0}\phi(A_0A_0^\star)A_0 \tag{8}$$

In the present investigation we have used variational theory to solve eq.(8) for q-Gaussian irradiance of the laser pulse.

$$A_0(x,y,z) = \frac{E_{00}}{f}\left\{1+\frac{r^2}{qr_0^2f^2}\right\}^{-\frac{q}{2}} \tag{9}$$

Here, $E_{00}$is the axial amplitude of the pulse, q is deviation parameter and f is dimensionless beam width parameter. The evolution equation of beam width is

$$\frac{d^2f}{dZ^2} = \left(\frac{c}{\omega_0 r_0}\right)^4\left[\frac{\left(1-\frac{1}{q}\right)\left(1-\frac{2}{q}\right)}{\left(1+\frac{1}{q}\right)}\frac{1}{f^3} - \left(1-\frac{1}{q}\right)\left(1-\frac{2}{q}\right)\left(\frac{\omega_{p0}^2 r_0^2}{c^2}\right)\frac{a_0^2}{f^3}I\right] \tag{10}$$

where,

$$I = \int_0^\infty u^3\left(1+\frac{u^2}{q}\right)^{-2q-1}\left(1+\frac{\beta E_{00}^2}{f^2}\left(1+\frac{u^2}{q}\right)^{-q}\right)^{-\frac{3}{2}}du$$

$$d' = dk_0r_0^2$$

$$u = \frac{r}{r_0 f}$$

$$Z = \frac{z\omega_0}{c}$$

$$a_0 = \frac{eE_{00}}{m_0\omega_0 c}$$

3. ELECTRON ACCELERATION

Equations of motion of electron are

$$\frac{dP_X}{dZ} = \left(1-\frac{\gamma}{P_Z}\right)\frac{a_0}{f}\left\{1\frac{(X^2+Y^2)c^2}{qr_0^2\omega_0^2f^2}\right\}^{-\frac{q}{2}}e^{-\frac{(T-Z)^2}{2\omega_0^2\tau_0^2}}\cos(T-Z) \tag{11a}$$

$$\frac{dP_Y}{dZ} = -\left(1-\frac{\gamma}{P_Z}\right)\frac{a_0}{f}\left\{1\frac{(X^2+Y^2)c^2}{qr_0^2\omega_0^2f^2}\right\}^{-\frac{q}{2}}e^{-\frac{(T-Z)^2}{2\omega_0^2\tau_0^2}}\sin(T-Z) \tag{11b}$$

$$\frac{dP_Z}{dZ} = \frac{a_0}{f}\left[-\left(\frac{P_X}{P_Z}\right)\cos(T-Z) + \left(\frac{P_Y}{P_Z}\right)\sin(T-Z)\right]\left\{1\frac{(X^2+Y^2)c^2}{qr_0^2\omega_0^2f^2}\right\}^{-\frac{q}{2}}e^{-\frac{(T-Z)^2}{2\omega_0^2\tau_0^2}} \tag{11c}$$

$$\frac{dX}{dZ} = \frac{P_X}{P_Z} \tag{11d}$$

$$\frac{dY}{dZ} = \frac{P_Y}{P_Z} \tag{11e}$$

$$\frac{dT}{dZ} = (\frac{\gamma}{P_Z} - 1) \tag{11f}$$

$$\gamma = \sqrt{1 + P_X^2 + P_Y^2 + P_Z^2} \tag{11g}$$

4. RESULTS and DISCUSSION

Eqs. (10)-(11) have been solved numerically for

$\omega_0 = 1.78 \times 10^{15}$rad/sec, $\tau_0 = 15 \times 10^{-15}$sec, $r_0 = 15\mu$m, $T(0) = 0.2$, $P_X(0) = 0.01$, $P_Y(0) = 0.01$,$P_Z(0) = 0.2$ and $q = (3, 4, \infty)$, $a_0^2 = 3$ and $\left(\frac{\omega_{p0} r_0}{c}\right)^2 = 9$.

Fig.1 depicts the variation of normalized electron energy with distance of propagation. It can be seen that initiallt the electron gain energy from the laser pulse almost linearly then after some distance of propagation its energy gets saturated with a little decrease from the maximum energy gained. Also with increase in deviation parameter q of the laser pulse the overall energy gained by the electron reduces.

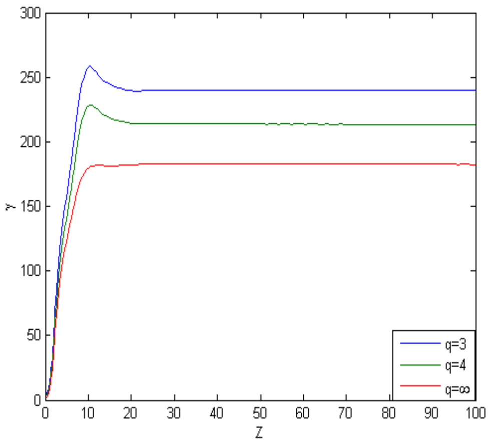

Fig.1: Evolution of electron energy with distance of propagation through plasma for $q = (3,4,\infty)$, $\left(\frac{\omega_{p0} r_0}{c}\right)^2 = 9$ and $a_0^2 = 3$.

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