CHAPTER-3

ELECTRON ACCELERATION BY A LASER PULSE IN VACUUM IN THE PRESENCE OF AZIMUTHAL MAGNETIC FIELD

3.1 INTRODUCTION

The laser particle interactions have remained an advancing research field for electron acceleration during last few decades. The detailed investigations of the laser driven acceleration of electron are focused on vacuum and plasmas which emerge with the vision for high energy gains [6, 15, 22, 70]. The plasma based schemes are capable to generate very high energy gain but constraint to suffer with plasma related instabilities. Electron acceleration by laser in vacuum [35] eliminates the difficulties associated with the plasma and makes it simple to inject an accelerated electron in vacuum than that in plasma. The dynamics for interaction of a relativistic electron with laser pulse was analysed theoretically by many scientist in the past [2, 11, 14, 26, 27, 51, 64, 78] and some experimentally effective models were proposed for verification [13, 54, 60, 105]. For a laser beam the group velocity is greater in vacuum than in plasma. This enhances the duration time for laser-electron interactions and leads to increase in the electron energy gain. Malka *et al.* [13] have analysed the results of experiment based on generation of electron of MeV energy by a linearly polarized (LP) ultra-intense laser pulse. They used a $1.056\mu m$, $300fs$ and $20J$ laser with peak intensity of $10^{19} W/cm^2$ for vacuum acceleration of electron. With such high intensity laser pulse, the electrons with few KeV of initial energy are accelerated to MeV energy.

The polarization remains an important character in laser-induced electron acceleration [58, 59, 96, 97]. For a LP laser pulse, the interaction factors of the laser with the electron are dependent on the polarization direction, whereas these parameters gets time averaged in circular polarization. This creates a wider interaction platform with a CP laser pulse. LP laser pulse is more efficient for the acceleration of a single electron whereas CP laser pulse is highly capable for electron bunch acceleration. The electrons decelerate earlier which are originated far from the propagation axis of the polarized laser pulse. Direct electron acceleration can be achieved by slow wave plasma structures [90] as well as by using radially polarized laser pulse [106]. With a radially polarized laser pulse an electron can gain a few GeV and retain a sufficient amount of energy through cyclotron oscillation in vacuum [66]. However, the electron gets de-phased with energy loss even with intense laser pulse. The characteristic variation in magnetic field [55, 89] helps in enhancing the electron energy gain. With an optimum static magnetic field the electron energy gain and retain can be enhanced. Gupta and Ryu [55] investigated the electron acceleration using an intense CP laser pulse under an obliquely incident applied magnetic field. They proposed the electron energy gain up to $10MeV$ without magnetic field and much higher MeV with an obliquely incident applied magnetic field. Liu and Tripathi [27] studied ponderomotive force directed acceleration of electrons in plasma. They proposed that the streams of energetic electrons produced by the ponderomotive force of laser which create a magnetic field. This self-generated and strong azimuthal magnetic field of the order of $100MG$ executes betatron oscillations and directs the electrons for high energy gain from laser. A high acceleration gradient of $2.286GeV/m$ was observed via cyclotron auto-resonance [108] using a laser peak intensity of about $10^{18}W/cm^2$ with an axial magnetic field of $60T$.

In this chapter we present an analysis on the results obtained from a relativistic 3D single particle simulation code for acceleration of electron by an intense laser pulse with an azimuthal magnetic field. It is based on the direct acceleration by a LP and CP laser beam in vacuum. In comparison with the earlier models presented by Gupta and Ryu [55] with obliquely incident magnetic field and Galow *et al.* [108] with axial magnetic field, we have employed an externally applied azimuthal magnetic field. We have seen the electron acceleration to a larger distance with higher acceleration gradient at comparatively low values of externally applied magnetic field. We analyse the relative efficiency of transfer of energy by CP and LP laser pulses. The strong fields of the laser pushes the electron forward at a suitable position of pulse peak and electron gets accelerated rapidly. The application of applied azimuthal magnetic field is highly supportive in maintaining the resonance between the electron and the laser field. The azimuthal magnetic field acts as a compressor for out phased electron, pinches the electron trajectory and enforces a confined trajectory for longer distance. Thus the electron gains higher energy and retains the same even after passage of the laser pulse for a larger distance. In section 3.4, we analyse the dynamics of an electron for a CP laser with azimuthal magnetic field. We solve numerically the coupled form of differential equations with the use of a relativistic code to understand the electron trajectory and electron energy gain. We discuss the numerical results in section 3.5. A brief conclusion of the work is presented in section 3.6.

3.2 FIELD DISTRIBUTION FOR LINEARLY AND CIRCULARLY POLARIZED LASER PULSES

We have considered a CP Gaussian profiled laser pulse with propagation direction along z-axis [51, 64]. The transverse (x, y) components representing the electric field are expressed as:

$$E_x = \frac{E_0}{f}\sin(\phi)\exp\left(-\frac{(t-\frac{z-z_L}{c})^2}{\tau^2}-\frac{r^2}{r_0^2 f^2}\right), \tag{3.1}$$

$$E_y = \varepsilon\frac{E_0}{f}\cos(\phi)\exp\left(-\frac{(t-\frac{z-z_L}{c})^2}{\tau^2}-\frac{r^2}{r_0^2 f^2}\right), \tag{3.2}$$

where E_0 is the peak amplitude of the laser, $\phi = \omega_0 t - k_0 z + \tan^{-1}(z/Z_R) - zr^2/(Z_R r_0^2 f^2) + \phi_0$, is the phase of laser pulse, $f^2 = 1+(z/Z_R)^2$, $k_0 = \omega_0/c$ is the wave number, ω_0 is the laser frequency, $Z_R = k_0 r_0^2/2$ is the Rayleigh length, ϕ_0 is the initial phase of laser pulse, τ is the laser pulse duration, $r^2 = x^2 + y^2$, r_0 is minimum laser spot size, z_L is the initial position of the laser pulse peak, and c is the velocity of light in vacuum. The factor ε represents the ellipticity and is equal to zero for a LP laser pulse. For a CP laser pulse $\varepsilon = \pm 1$ represents the positive and negative helicity. Here we have considered $\varepsilon = +1$ for CP laser pulse.

The intensity of CP laser pulse can be expressed in terms of intensity of LP laser pulse as: $I_{CP} = I_{LP}(1+|\varepsilon|)$. The amplitude of parallel component of electric field is very small as compare to perpendicular components for large beam width. We chose laser spot size $r_0 = 900$ for which the parallel component of laser field can be neglected [64].

The components of lasers magnetic field can be derived by using Maxwell's equations and are expressed in terms of equation:

$$\vec{B} = c\,\frac{\vec{k}_0 \times \vec{E}}{\omega_0}\,. \tag{3.3}$$

3.3 AZIMUTHAL MAGNETIC FIELD

To strengthen the electron acceleration we apply an external magnetic field which improves the $\vec{v} \times \vec{B}$ force crucial for electron acceleration. We consider azimuthal magnetic field suitable for this purpose, which additionally binds the electron trajectory. Liu and Tripathi [53] proposed the existence of a self-generated $100MG$ magnetic field during laser plasma interaction, which is azimuthal in nature. It is possible to apply the magnetic field from external magnetic source in vacuum. A scheme for the generation of azimuthal magnetic field was proposed by Takakura *et al.* [93]. The azimuthal magnetic field [27] is represented as:

$$\vec{B}_\theta = (y\hat{x} - x\hat{y})\,\frac{B_0}{r_0}\exp\left(-\frac{r^2}{r_0^2}\right), \tag{3.4}$$

where B_0 is the peak value of magnetic field. This field increases from a minimum value at $r = 0$ to maximum value at $r \sim r_0$. For the case of LP laser pulse with only x directed transverse, the azimuthal magnetic field [73] experienced by electron can be obtained by substituting $y = 0$ in Eq. (3.4).

Figure 3.1 shows a schematic diagram of acceleration of electron by a short pulse laser with an azimuthal magnetic field in vacuum. Fig. 3.1(a) shows the angle δ at which the electron is injected with respect to the direction parallel to the propagation of laser pulse. Fig. 3.1(b) shows the direction of externally applied azimuthal magnetic field. This field encircle the trajectory of accelerated electron.

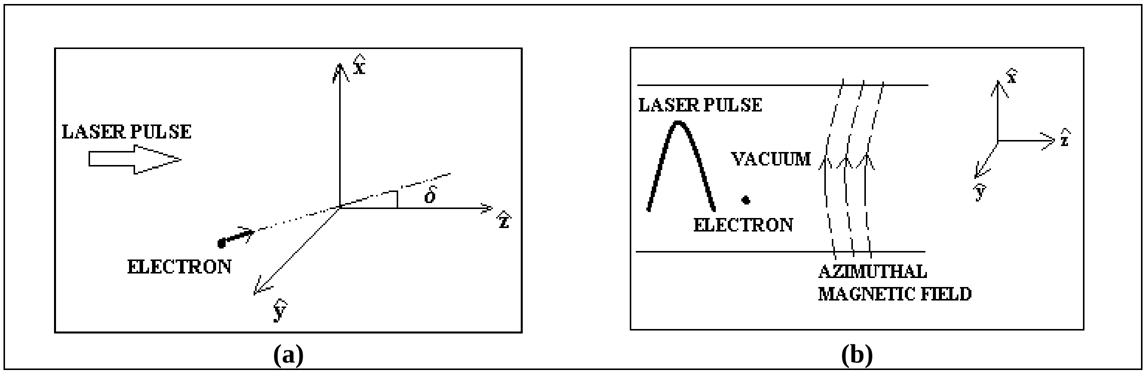

Figure 3.1. Schematic of laser induced acceleration of electron in vacuum with azimuthal magnetic field. (a) The angle δ at which the electron is injected with respect to the direction parallel to the propagation of laser pulse and (b) The direction of external azimuthal magnetic field.

3.4 ELECTRON DYNAMICS AND RESONANCE CONDITION

The electron momentum and energy is governed by following equations:

$$\frac{dp_x}{dt} = -eE_x + e\beta_z B_y + e\beta_z B_{\theta y}, \qquad (3.5)$$

$$\frac{dp_y}{dt} = -eE_y - e\beta_z B_x - e\beta_z B_{\theta x}, \qquad (3.6)$$

$$\frac{dp_z}{dt} = -e(\beta_x B_y - \beta_y B_x) - e(\beta_x B_{\theta y} - \beta_y B_{\theta x}), \qquad (3.7)$$

$$\frac{d\gamma}{dt} = -e(\beta_x E_x + \beta_y E_y), \qquad (3.8)$$

where (p_x, p_y, p_z) are the (x, y, z) coordinates of the momentum $\vec{p} = \gamma m_0 \vec{v}$; ($\beta_x, \beta_y, \beta_z$) are the ($x, y, z$) coordinates of the normalized velocity $\vec{\beta} = \vec{v}/c$; $\gamma^2 = 1 + (p_x^2 + p_y^2 + p_z^2)/(m_0 c)^2$ is the Lorentz factor, $-e$ is the electron's charge, and m_0 the rest mass of electron.

The other dimensionless variables are:

$$a_0 \rightarrow \frac{eE_0}{m_0 \omega_0 c},\ \tau' \rightarrow \omega_0 \tau,\ r_0' \rightarrow \frac{\omega_0 r_0}{c},\ z_L' \rightarrow \frac{\omega_0 z_L}{c},\ x' \rightarrow \frac{\omega_0 x}{c},\ y' \rightarrow \frac{\omega_0 y}{c},\ z' \rightarrow \frac{\omega_0 z}{c},$$

$$\beta_x \to \frac{v_x}{c},\ \beta_y \to \frac{v_y}{c},\ \beta_z \to \frac{v_z}{c},\ t' \to \omega_0 t,\ p_0' \to \frac{p_0}{m_0 c}, p_x' \to \frac{p_x}{m_0 c},$$

$$p_y' \to \frac{p_y}{m_0 c},\ p_z' \to \frac{p_z}{m_0 c},\ k_0' \to \frac{ck_0}{\omega_0}, \text{and } b_0 \to \frac{eB_0}{m_0 \omega_0 c}.$$

Equations (3.5)-(3.8) are the coupled ordinary differential equations. These equations have been solved numerically to obtain the trajectory and energy of electron.

The electron is assumed to be injected in the path of laser pulse at a small angle δ with respect to the z-direction [55]. The initial momentum p_0 of the electron is expressed as $\vec{p}_0 = \hat{x} p_0 \sin\delta + \hat{z} p_0 \cos\delta$.

Resonance occurs when the laser frequency $(\omega_0 - k_0 v_z)$ coincides with betatron frequency ω_b. The betatron oscillation frequency [78] can approximately be obtained from the transverse motion of electron, where $\omega_b = \sqrt{e v_x B_0 / \gamma m_0 r_0 c}$. Thus with $\omega_b = \omega_0 - k_0 v_z$ the resonance condition is written as,

$$\frac{eB_0}{m_0 r_0 \omega_0^2} = \frac{\gamma\, c}{v_z}\left[1 - \frac{k_0 v_z}{\omega_0}\right]^2. \tag{3.9}$$

The resonance condition specifies that the laser frequency decreases with time to maintain the resonance for longer duration. This keeps the electron accelerating with higher energy gain. For a small increase of v_z, the factor $(1 - v_z k_0 / \omega_0)$ decreases. This decreases ω_b and hence γ increases. For a pre-accelerated electron the increase in v_z remains small. This extends the maximum duration of resonance between laser pulse and electron. Hence electron maintains high energy gain for longer duration.

3.5 RESULTS AND DISCUSSION

For simulations and calculations, the numerical values of dimensionless parameters are expressed as: $a_0 = 2.5$ (corresponds to laser intensity $I \sim 8.5 \times 10^{18} W/cm^2$ for a LP laser pulse and $I \sim 1.7 \times 10^{19}\ W/cm^2$ for a CP laser pulse), $a_0 = 5$ (corresponds to laser intensity $I \sim 3.46 \times 10^{19}\ W/cm^2$ for a LP laser pulse and $I \sim 6.92 \times 10^{19}\ W/cm^2$ for a CP laser pulse) and $a_0 = 7.5$ (corresponds to laser intensity $I \sim 7.65 \times 10^{19}\ W/cm^2$

for a LP laser pulse and $I \sim 1.53\times10^{20}\,W/cm^2$ for a CP laser pulse) with wave length $\lambda_0 \sim 1\mu m$; $r_0' = 900$ (corresponds to laser spot sizes $r_0 \sim 151\mu m$); and $p_0' = 1$, 1.5, 2 and 2.5; $\tau' = 70$ (corresponds to pulse duration of $200fs$); $\delta = 10^\circ$; $\phi_0 = 0$; $b_0 = 0.005$ (corresponds to a magnetic field of $534kG$), $b_0 = 0.018$ (corresponds to a magnetic field of $1.9MG$) and $b_0 = 0.005$ (corresponds to a magnetic field of $534kG$); and $z_L' = -300$.

Figure 3.2, shows the trajectory of electron in 3D plane without ($b_0 = 0$) and with ($b_0 = 0.005$) azimuthal magnetic field for $a_0 = 2.5$ and $p_0' = 2.5$ with LP and CP laser pulse. Fig 3.2(a) and 3.2(b) show the trajectory of electron without magnetic field. During interaction with laser pulse, the electron gets accelerated and suddenly decelerated within small distance. The electron goes out of phase and lost its energy. As represented in fig. 3.2(c) and 3.2(d), a confined trajectory is observed with azimuthal magnetic field. The electron rotates around the direction of propagation of laser pulse. The radius of rotation of electron increases rapidly with the energy gain. The presence of additional magnetic field improves the value of $\vec{v}\times\vec{B}$ force. It was suggested by Gupta and Ryu [55] that the electron travel more distance along the direction parallel to propagation of laser pulse with an external magnetic field, which is obliquely incident and of normalized values $b_0 = 0.1$ and 0.01. We observe that the electron not only traverses more distance but also retains high energy with the normalized value $b_0 = 0.005$ of azimuthal magnetic field. The azimuthal magnetic field enforces a constant radius of rotation for larger distance by pinching the out of phase electron towards the $+z$ direction and hence, contributes in retaining of higher energy at larger distances. From fig. 3.2(c) and 3.2(d), it appears that the electron acceleration with a CP laser pulse is more effective than that with a LP laser pulse. The CP pulse provides a wider platform for the interaction of laser with electron than that with a LP pulse. Hence, a better trajectory of electron appears with a CP laser pulse. Further the radius of rotation during electron acceleration with CP pulse appears greater than that with LP pulse which indicates the higher energy gain with CP pulse.

Figure 3.3, shows the plots of energy gain γ by electron for LP and CP laser pulses with normalized magnetic field b_0. In Fig. 3.3(a) and 3.3(b), γ has been analysed

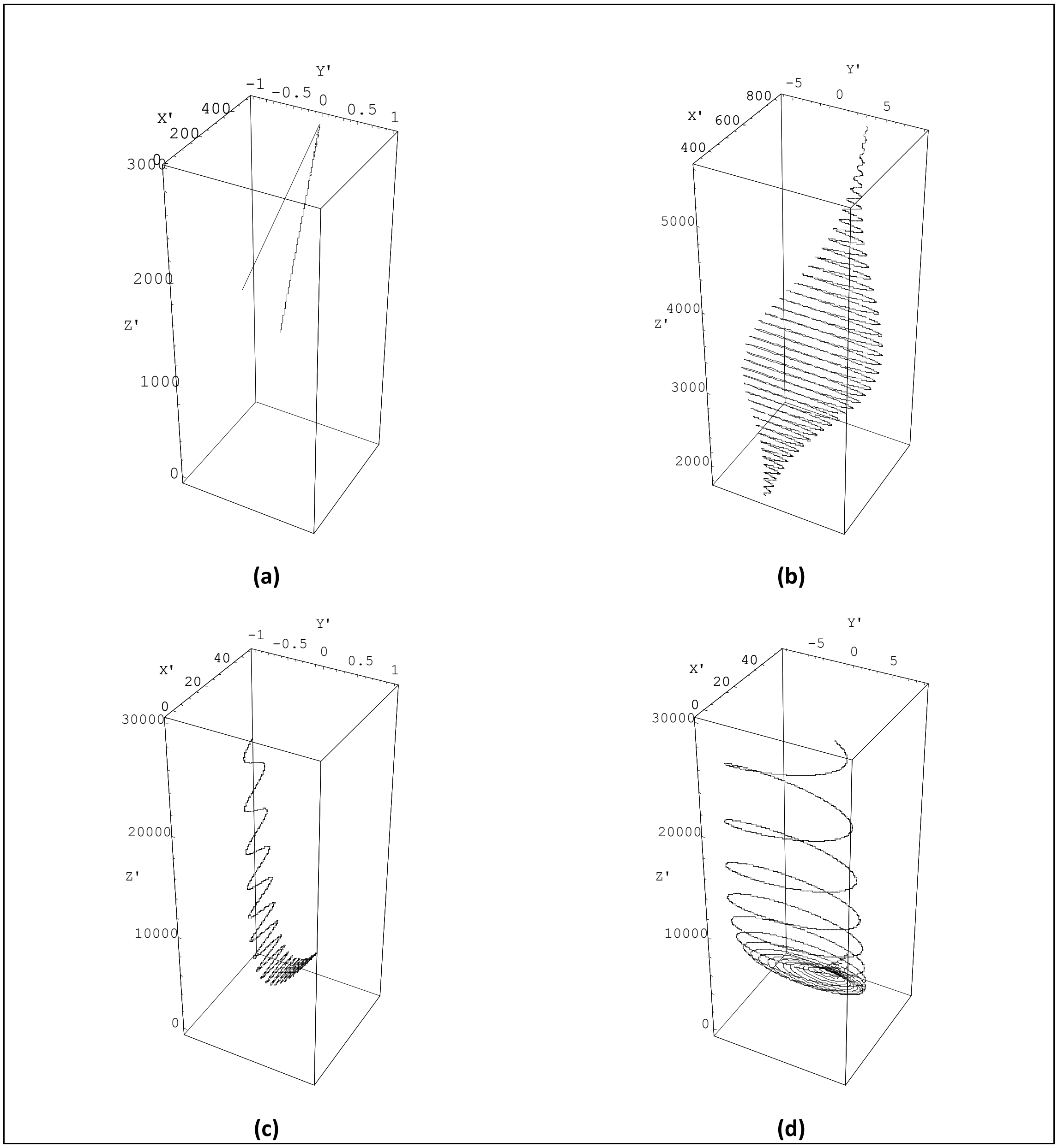

Figure 3.2. Trajectory of electron in 3D plane without and with magnetic field for $a_0 = 2.5$ and $p_0' = 2.5$. (a) $b_0 = 0$ with LP, (b) $b_0 = 0$ with CP, (c) $b_0 = 0.005$ with LP, and (d) $b_0 = 0.005$ with CP laser pulse. The other parameters are $r_0' = 900$, $\tau' = 70$, $\delta = 10^\circ$, $\phi_0 = 0$, and $z_L' = -300$.

at distinct values of normalized initial electron momentum for $a_0 = 2.5$ and 5. Fig. 3.3(c) shows the variation plots for energy gain γ with b_0 for distinct values of laser intensity parameter $a_0 = 5$, 6, and 7.5 at $p_0' = 1$. The energy gain is observed to be higher at the smaller values of magnetic field. An electron is introduced at a small angle with respect to z-direction of propagation of laser pulse, traps with laser pulse with low magnetic field. The values of these magnetic fields appear as optimum values for a set of parameters. The energy gain by an electron, after reaching its maximum value at these optimum values of magnetic field, decreases initially and almost saturates for the larger values of magnetic field. The energy gain is maximum at these small values due to resonance between the electron and laser field. The energy gain increases with laser pulse intensity and decreases with initial momentum as acceleration gradient decreases with initial momentum and increases with laser pulse intensity [64]. For a strong resonance at optimum value of magnetic field the acceleration gradient increases with decrease in initial momentum. Thus higher energy gain appears at smaller values of initial momentum as appearing in fig. 3.3(b) for CP laser pulse. For $a_0 = 5$, the higher energy gain $\gamma = 2781$ appears at $b_0 = 0.003$ with $p_0' = 2$ which is higher than that of $\gamma = 2636$ at $b_0 = 0.006$ with $p_0' = 2.5$. The energy gain remains higher for $a_0 = 7.5$ than $a_0 = 6$ and $a_0 = 5$. Further, it is clear from fig. 3.3(c) that the resonance occurs at the low values of magnetic field even for high laser intensity parameter. Hence, the optimum values of magnetic field play a vital role in achieving the resonance for higher energy gains.

Figure 3.4, shows the plots of energy gain γ by electron with the normalized distance z'. In fig. 3.4(a) and 3.4(b), we observe the variation of γ with z' for distinct values of normalized electron momentum $p_0' = 1.5$, 2, and 2.5 with optimized magnetic field for $a_0 = 2.5$ and 5. Fig. 3.4(c) shows the variation plot of energy gain γ by electron with z' with the optimum values of applied magnetic field at $p_0' = 1$ for $a_0 = 5$, 6, and 7.5. For the optimum magnetic field and initial momentum, the electron energy gain increases with distance due to resonance and an electron interacts with laser pulse efficiently at a particular position of peak of the pulse. At that position, there is a

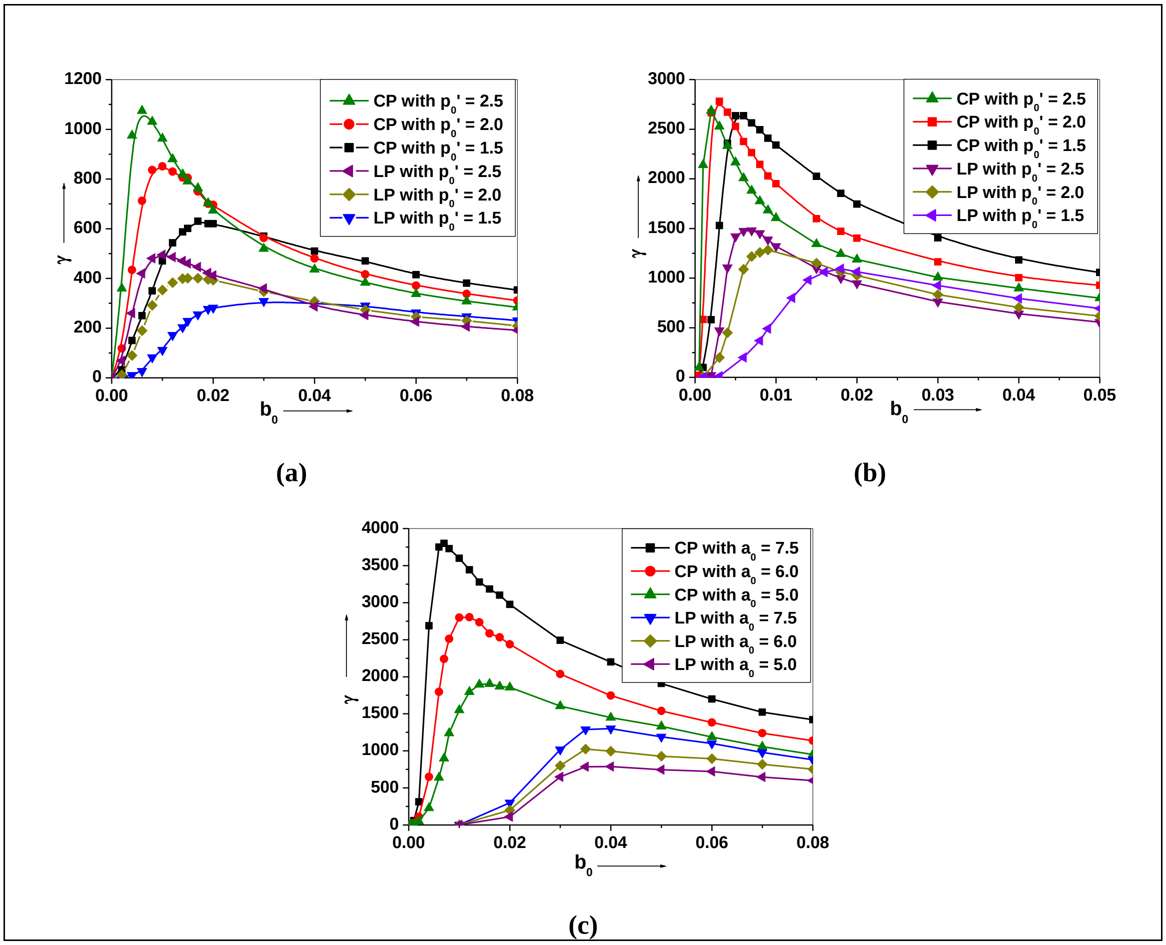

Figure 3.3. Electron energy gain γ with normalized magnetic field b_0 for distinct and normalized values of initial momentum and intensity parameter for LP and CP laser pulses. (a) $p_0'=1.5$, 2 and 2.5 at $a_0=2.5$, (b) $p_0'=1.5$, 2 and 2.5 at $a_0=5$, and (c) $a_0=5$, 6, and 7.5 at $p_0'=1$. The rest of the parameters are same as referred in fig. 3.2.

maximum transfer of energy from the laser to the electron in vacuum. Electron energy gain of $252MeV$ is seen with laser intensity parameter $a_0=2.5$ in the presence of $b_0=0.009$ with LP pulse. An enhanced energy gain of $549MeV$ is observed with $a_0=2.5$ in the presence of $b_0=0.006$ with a CP laser pulse. The peak value of laser intensity $7.65\times10^{19}\,W/cm^2$ corresponds to normalized intensity parameter $a_0=7.5$ for a LP laser pulse and $a_0\cong5$ for CP laser pulse. The maximum energy gain with this intensity is about $664 MeV$ with LP and about $1 GeV$ with CP laser pulse. Thus the energy gain remains high with a CP laser pulse in comparison with LP laser pulse with azimuthal magnetic field in vacuum. It is because of the wider interaction of CP laser pulse with electron than that with LP laser pulse. After attaining the maximum value, the energy gain remains constant for larger distances due to the setting of betatron oscillations between the accelerating electron and lasers electric field. The accelerating distance with a CP laser pulse is observed to be 2 times greater than that with a LP laser pulse for the same intensity values. The electron retains the maximum energy due to the presence of azimuthal magnetic field for larger distances even after passing of the laser pulse.

Gupta *et al.* [66] proposed that after gaining significant energy form laser pulse, the electron gets decelerated with energy lose and left with a small energy of about $25 MeV$ for laser intensity parameter $a_0 = 5$. For a significant high energy gain, an intense laser pulse [73] was employed for another set of parameters with normalized magnetic field parameter $b_0 = 1.5$. In the present study a significant enhancement in the electron energy is observed in with a comparatively smaller magnetic field, $b_0 = 0.003$ (corresponding to a value of $320 kG$) with laser intensity parameter $a_0 = 5$. We find a high energy gain of $1.42 GeV$ using a CP laser pulse with azimuthal magnetic field.

Hu and Starace [57] reported about $100 MeV$ retainable energy with a LP laser of very high peak intensity of $2 \times 10^{22} W / cm^2$. Such high intensity peak corresponds to intensity parameter $a_0 = 100$. In our scheme a much higher GeV energy can be achieved using such a high intensity laser pulse with an external azimuthal magnetic field. From fig. 3.4(c), we observe that an energy gain of $1.96 GeV$ with $a_0 = 7.5$ (corresponds to peak intensity of $1.53 \times 10^{20} W / cm^2$ for a CP laser pulse) with $b_0 = 0.007$(corresponds to magnetic field of $750 kG$). The normalized magnetic field $b_0 = 0.007$ is an optimized value of azimuthal magnetic field for high energy gain. Such a value of applied magnetic field is feasible and can be achieved experimentally. Certain experimental observations reported the generation of magnetic field of the order of MG [93, 115].

Figure 3.5, shows the plots of normalized velocity components β with normalized accelerating distance z'. The initial value of transverse velocities β_x and β_y

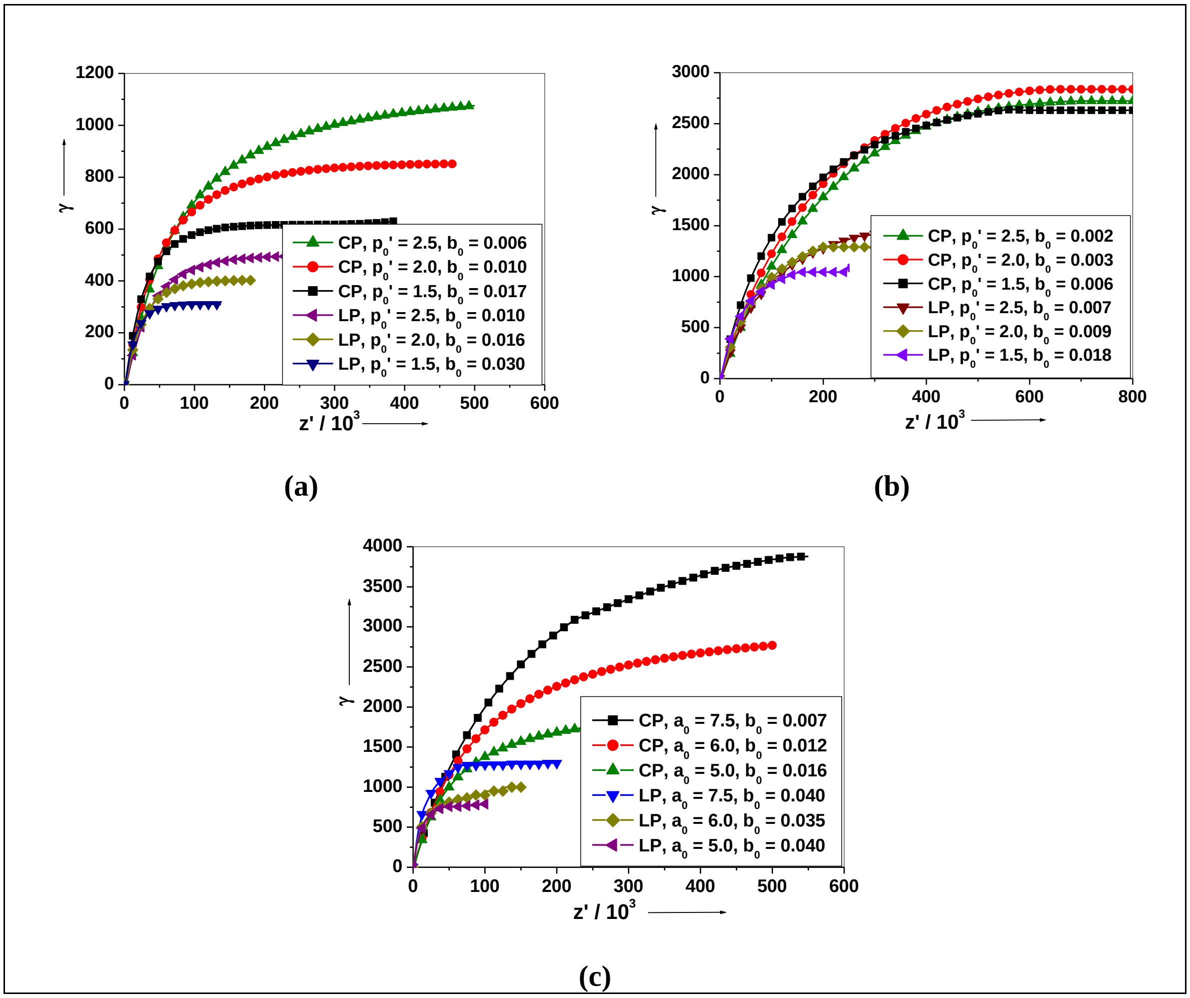

Figure 3.4. Electron energy gain γ with normalized propagation distance z' for distinct values of magnetic field for LP and CP laser pulses. (a) $p_0'=1.5$, 2 and 2.5 at $a_0=2.5$, (b) $p_0'=1.5$, 2 and 2.5 at $a_0=5$, and (c) $a_0=5$, 6, and 7.5 at $p_0'=1$. The rest of parameters are same as referred in fig. 3.2.

goes on decreasing with distance z' whereas the longitudinal velocity β_z rises quickly which indicates the electron acceleration in longitudinal direction of laser field. The momentum of ejected electron is related with emittance angle θ. It is the maximum angle at which the electron is ejected out with respect to propagation axis. Using relation $\tan\theta=(p_x^2+p_y^2)^{1/2}/p_z$ with Lorentz force factor, the angle of emittance with respect to

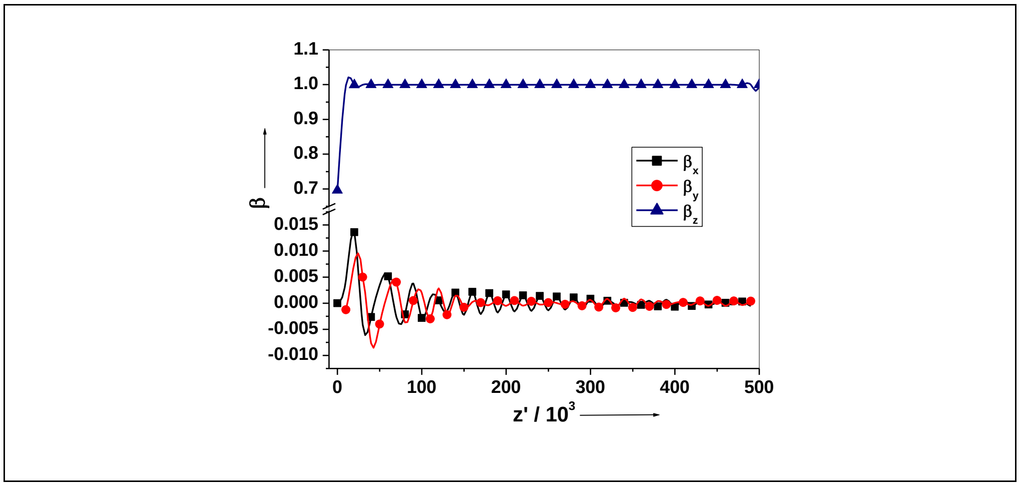

Figure 3.5. Normalized parallel velocity β_z and perpendicular velocities β_x and β_y with normalized propagation distance z' for CP laser pulse with $a_0 = 10$, $p_0' = 1.5$, and $b_0 = 0.005$. The rest of the parameters are same as taken in fig. 3.2.

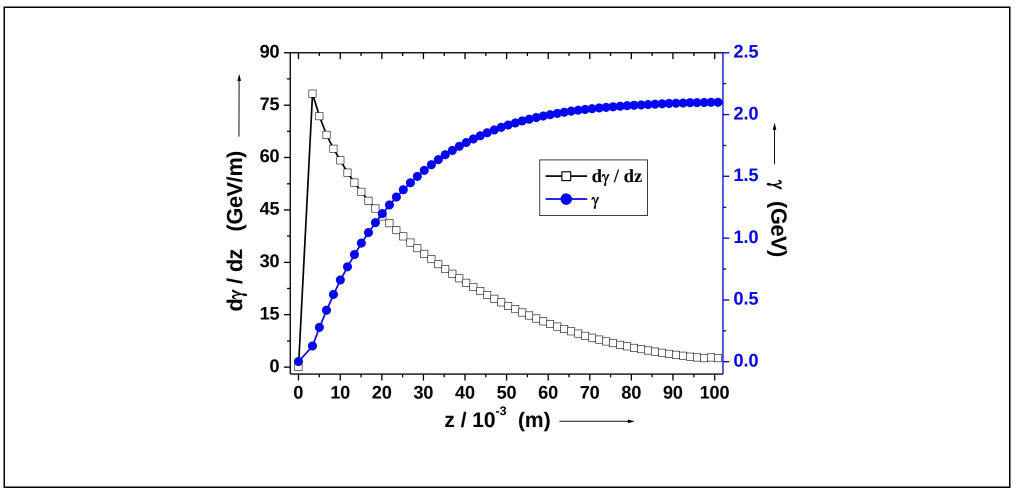

Figure 3.6. Acceleration gradient $d\gamma / dz$ and energy gain γ with accelerating distance z for CP laser pulse with $a_0 = 10$, $p_0' = 1.5$, and $b_0 = 0.005$. The other parameters are same as taken in fig. 3.2.

the propagation axis (z) is expressed as $\theta = \tan^{-1}(\sqrt{(\gamma^2 - 1)/(\gamma^2 \beta_z^2) - 1})$. For an energy gain of $1.96 GeV$ with $a_0 = 7.5$ the angle θ is 0.32° and for energy gain of $2.1 GeV$ with

$a_0 = 10$ the angle θ is 0.27°. The observed values of angle of emittance remain small for higher energy gain.

Figure 3.6, shows the plots of acceleration gradient $d\gamma / dz$ and energy gain γ with accelerating distance z. The acceleration gradient [108] is calculated by using relation $d\gamma / dz = -e\vec{\beta}.\vec{E} / \beta_z$ and is drawn as a function of accelerating distance z for a CP laserpulse with $a_0 = 10$, $p_0' = 1.5$ and $b_0 = 0.005$. The maximum acceleration gradient of $76 GeV / m$ is observed with $a_0 = 10$. The maximum energy gain of $2.1 GeV$ is observed with this peak intensity of $2.74 \times 10^{20} W / cm^2$. The higher acceleration gradient and higher energy gain by electron is observed with higher intensity laser pulse.

3.6 CONCLUSION

We have investigated the dynamics of electron due to LP and CP laser pulses, under the externally applied azimuthal magnetic field in vacuum. An electron originated off axis with finite velocity follow approximately straight line path, does not return to the actual axis for propagation and hence, does not gain energy. With the azimuthal magnetic field the electron moving away the z-axis and experiences a $\vec{v} \times \vec{B}$ force which keeps the electron to traverse rotating motion along z-axis. Resonance occurs at optimum values of magnetic field which lead to an efficient exchange of energy between the accelerated electron and laser's electric field. Energy exchange is more significant with a CP pulse at higher values of laser intensity and at optimum values of azimuthal magnetic field. A pre-accelerated electron on interaction with laser pulse of low intensity can gain few MeV of energy with a small magnetic field. An electron with $1 MeV$ of initial energy can gain energy of the order of $2.1 GeV$ from a CP laser pulse of higher intensity in the presence of very small magnetic field. Therefore, with the suitable values of parameters like intensity of laser pulse, initial momentum of electron and static magnetic field, the higher energy gain of the order of GeV is achievable with an electron of few MeV of initial energy.