CHAPTER-12

SUMMARY AND CONCLUSION

In this study we have investigated the electron dynamics with polarization effects, frequency variations, and variation of other parametric characters of laser pulses. The features determining the electron dynamics in terms of electrons initial position, injection and initial energy have been analysed for laser electron interaction. We have also explored the role of external magnetic field in obtaining the higher electron energy gain.

We have investigated the dynamics of electron by LP and CP laser pulses in the presence of 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. In the presence of azimuthal magnetic field the electron moving away from 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 leads to an efficient exchange of energy between the accelerated electron and laser's electric field. Energy exchange is more significant with a CP laser pulse at higher values of laser intensity and at optimum values of magnetic field. The presence of azimuthal magnetic field with the higher value of CP laser intensity, specific initial momentum, not only enhances the energy gain by the electron but also keeps it for larger distance. A pre-accelerated electron on interaction with laser pulse of low intensity can gain few MeV of energy in the existence of a small magnetic field. An electron with $1MeV$ of initial energy can gain energy of the order of $2.1GeV$ from a CP laser pulse of high intensity in the presence of very small magnetic field. Thus with the suitable values of parameters like laser pulse intensity, initial electron momentum and static magnetic field the higher energy gain of the order of GeV can be achieved with an electron of few MeV of initial energy.

In recent years, there is much attention in accelerating the electrons by chirped laser fields in vacuum. We have additionally seen the influence of azimuthal magnetic field on electron acceleration with a LP chirped laser pulse. Our results highlight the importance of chirping of laser pulse in the presence of azimuthal field for enhanced electron acceleration. We have presented that an electron with approximately $2.5 MeV$ of initial energy can gain energy of about $1.47 GeV$ from a LP chirped laser pulse in the presence of relatively small azimuthal magnetic field. Thus, with suitable selection of parameters like laser pulse intensity, initial electron momentum, static magnetic field and chirp factor, the higher energy of the order of GeV can be achieved with an electron of few MeV of initial energy. The presented model led to a substantial increase in electron acceleration energy.

Present study highlights the importance of chirped CP laser pulse and azimuthal magnetic field to obtain high electron energy gain in vacuum. We have observed an energy gain of $\gamma = 5210$(corresponding to $2.66 GeV$) for laser intensity $a_0 = 20$ (corresponding to $2.74 \times 10^{20} W/cm^2$) with chirp parameter $\alpha' = 0.00065$ in the presence of azimuthal magnetic field $b_0 = 0.000875$ (corresponding to $94 kG$). Thus, a pre-accelerated electron of few MeV of initial energy can be accelerated up to GeV energy with optimized laser and magnetic field parameters as we have analyzed in the present study.

Our model specifies the effect of an axial magnetic field on electron acceleration by a RP laser in vacuum. We have found that a high intensity RP laser pulse can accelerate a rest electron in the direction parallel to propagation of laser pulse with small scattering. We have observed the relativistic electron acceleration to GeV energies in vacuum. The electron energy is further enhanced in the presence of axial magnetic field. The unique characteristics of RP beams with cylindrical symmetry in comparison with linearly or circularly polarized beams support better acceleration of charged particles. The axial magnetic field enforces better trapping during interaction of electron with laser pulse. We have observed the sensitiveness of axial magnetic field on electron energy gain. An enhancement in electron energy gain with a relatively smaller scattering appears with axial magnetic field of small and optimum values. We have observed 70% enhancement in electron energy with axial magnetic field than in the absence of magnetic field.

We have seen the electron acceleration in vacuum to GeV energy by a RP chirped laser. In the absence of chirping the accelerated electron after attaining maximum energy gets out of phase with the field. The presence of a linear chirp not only improves the electron energy gain but also support in retaining the gained energy for longer distances. This is because the chirping increases the duration of electron laser interactions and hence maintains the betatron resonance for longer distances. We have observed about 2.5 times higher energy gain with a linearly chirped RP laser pulse than that with an unchirped RP laser pulse. An effective enhancement in electron energy gain with a periodic chirp relative to a linear chirp for RP laser pulse is obtained. The maximum energy gain from a periodic chirp is almost twice that of a linear chirp. The chirp parameters are sensitive to the electron energy gain and small change in chirp parameter can affect the electron acceleration significantly. Sensitiveness of chirp parameters is very crucial in electron acceleration and it would undoubtedly be a key factor in achieving maximum electron energy gain. Further, the value of angle of electron ejection appears to be low with a high intensity periodically chirped laser pulse for higher energy gains. We have achieved an energy gain of about $10.5 GeV$ with laser intensity $a_0 = 100$ (corresponding to laser intensity $I \sim 1.36 \times 10^{22}\, W/cm^2$) for optimum periodic chirp parameters with a RP laser pulse in vacuum.

We have also observed electron acceleration to GeV energy by a RP laser pulse in vacuum in the presence of wiggler magnetic field. In the absence of wiggler magnetic field the accelerated electron after attaining maximum energy gets out of phase with the field and loses its gained energy quickly. The presence of a wiggler magnetic field not only increases the electron energy gain but also supports in retaining the gained energy for longer distances. We have observed about 4 times higher energy gain in the presence of wiggler magnetic field with a RP laser pulse than that in the absence of wiggler magnetic field. An effective enhancement in electron energy gain is observed with a sideway injection of electron at a small angle of about 10° with respect to the direction parallel to propagation of laser pulse than that with axial injection. The maximum energy gain with a sideway injection is about 1.3 times higher than that with axial injection.

We analyse the influence of beam width parameter on electron acceleration by with a CP Gaussian laser pulse in magnetized plasma. We compare the acceleration distance in term of Rayleigh length for different values of laser beam spot size and laser intensity parameters. The greater count of Rayleigh length in terms of propagation distance is observed for a smaller beam spot size and vice versa. The electron gain high energy with small beam width parameter due to strong laser field and loss energy with large beam width due to weak field with large propagation distance. The externally applied axial magnetic field supports the retaining of high energy by electron for large distance. We obtain a very high acceleration gradient with small ejection of electrons due to axial magnetic field in plasma.

We have investigated the effect of laser beam width parameter and mode indices of Hermite-Gaussian laser beam on electron acceleration with variation of laser intensity. We have presented the role of different modes on the electron energy gain. Though, the energy gain with higher modes remains high but the electron de-phased at shorter distance. With an appropriate selection of laser beam spot size, and mode index, the electron can be accelerated to the order of GeV energy.

Finally, we have investigated the effect of LP and CP laser pulse on electron acceleration during laser-cluster interaction. We have applied a wiggler magnetic field to improve the acceleration process by laser field in cluster. The wiggler magnetic field enforces better trapping during interaction of the electron with laser pulse. A significant enhancement in electron energy gain is observed with a wiggler magnetic field of small and optimum values. We have observed the relativistic electron acceleration to MeV energies in laser-cluster interaction.

In conclusion, the presented models and simulation results will be a great help for experimentalists to use the appropriate parameter for higher electron energy gain while laser electron interactions. The laser driven electron acceleration to high energy finds a wide range of applications, such as, therapy for treatment of tumors, medicine, radiation driven chemistry, material characterization, border security through detection of explosives, narcotics and other dangerous substances and ultrafast phenomena studies.