THE STUDY OF PROPAGATION OF GAUSSIAN LASER BEAM IN COLLISION-LESS MAGNETIZED PLASMA

T. U. Urunkar*
C. J. Kambale**
S. V. Malgaonkar***
G. J. Nawathe****
M. M. Karanjkar*****

Abstract :

It is quite known that critical beam radius plays vital role in propagation of Gaussian laser beam in collisionless magnetized plasma under ponderomotive nonlinearity. In present investigation effect of electron cyclotron frequency on critical curve as well as on self-focusing has been explored by using Parabolic Wave equation Approach under Paraxial Ray Approximation.

Keywords : Self-focusing, Gaussian, magnetized plasma, beam radius, critical beam power,

Introduction

Interactions of high intensity laser beam with plasma have wide veriety of applications such as laser particle acceleration (Malka V. 2012), fast ignition for inertial confinement fusion (Atzeni S. 2015). Self-focusing phenomenon plays a crucial role in the origin of other nonlinear phenomena and hence is important for theoretical investigations.

The experimental and theoretical investigations on self-focusing of laser beams in plasmas have been studied extensively in case of a Gaussian beam (Kourakis I. 2010, Program R. F. 2009, Aggrawal M. 2009, Sharma A. K. 2009). Additionally, of super Gaussian beam (Alexander L. 2006), degenerate modes of beams (Karlsson M. 1992), Bessel beams (Trapani P. D. 2004), Laguerre–Gaussian beams (Berakdar J. 2010) and dark hollow Gaussian beams (Mishra S. K. 2009) have been also studied along with the usual Gaussian beam.

Different kind of theoretical approaches such as moment theorotic approach (Firth W. J. 1977), Akhmanov"s coupled equation approach (Tripathi V. K. 1976) and source-dependent expansion approach are already in use extensively to analyse the phenomenon of self-focusing. But, the most popular

* *Department of Physics, Vivekanand College, Kolhapur truptiu16@gmail.com*

theoretical approach under Wentzel–Krammers–Brillouin and PRA approximation given by Akhmanov and developed by Sodha has been adopted by us for theoretical investigations reported here.

In present investigation authors have explored effect of electron cyclotron frequency on critical curve as well as on self-focusing by considering ponderomotive nonlinearity.

Organization of the paper comprises following sections: The Sec. II gives theoretical framework. Results and discussion are given in Sec. III. Finally, in Sec. IV, conclusions of the present theoretical investigation are presented.

THEORETICAL FRAMEWORK

In the light of Maxwells elctrodynamics equations in esu system, the general form of wave equation governing the propagation of cosh Gaussian laser beam is given as,

$$\frac{\partial^2 E_\pm}{\partial z^2}+\delta_\pm\left(\frac{\partial^2 E_\pm}{\partial r^2}+\frac{1}{r}\frac{\partial E_\pm}{\partial r}\right)+\frac{\omega^2}{c^2}\left(\varepsilon_\pm E_\pm\right)=0 \qquad (1)$$

Where,

$$\delta_\pm=\frac{1}{2}\left(1+\frac{\varepsilon_{0\pm}}{\varepsilon_{0zz}}\right) \quad \text{and}$$

$$\varepsilon_{0zz}=1-\frac{\omega_p^2}{\omega^2}$$

The effective dielectric constant of magnetized plasma can be written as,

$$\varepsilon_\pm=\varepsilon_{0\pm}+\Phi_\pm(EE^*) \qquad (2)$$

where $\varepsilon_{0\pm}$ and $\Phi_\pm(E_\pm E_\pm{}^*)$ are the linear and nonlinear parts of the dielectric constant of collisionless magnetized plasma and can be expressed as,

$$\varepsilon_{0\pm}=1-\frac{\omega_p^2}{\omega(\omega\mp\omega_c)} \qquad (3)$$

$$\Phi_\pm(E_\pm E_\pm{}^*)=\frac{\omega_p^2}{2\omega(\omega\mp\omega_c)}\left[1-\exp(-\alpha E_\pm E_\pm{}^*)\right] \qquad (4)$$

Here, $\omega_p=\left(4\pi N_0e^2/m\right)^2$ is the plasma frequency and $\omega_c=eB_0/m_0c$ is cyclotron frequency. e and m are the electronic charge and rest mass respectively. Here $\xi_\pm=z/k_\pm r_0^2$ is normalized propagation distance. $\alpha=3m\alpha_0/4M$, $\alpha_0=e^2/6m\omega^2k_BT_0$, N_0 be the unperturbed density of plasma electrons, m is the mass of ion, ω is the angular frequency of laser used, k_B is the Boltzmann constant, B_0 is static magnetic field and T_0 is a equilibrium plasma temperature.

Within the framework of WKB and paraxial approximations, for , energy conserving ansatz for the intensity distribution of Gaussian laser beam propagating along z axis is given by

$$A_{0\pm}^2=\frac{E_{\pm0}^2}{f^2}\left(\frac{-r^2}{r_0^2 f_\pm^2}\right) \qquad (5)$$

Where $E_{\pm 0}^2$ is an initial laser intensity and $f_\pm$ is the dimensionless beam width parameter. Following approach given by Akhmanov et al. [20] and developed by Sodha et al. [19] we have obtained the dimensionless beam-width parameters as,

$$\frac{\partial^2 f_\pm}{\partial \xi_\pm^2} = \frac{1}{\varepsilon_{0\pm}} \frac{1}{f_\pm^2}\left(\frac{12\delta_\pm^2}{3} - \frac{\exp[-p_\pm]\rho_\pm^2 \gamma_\pm \delta_\pm}{2}\right) \quad (6)$$

where,

$$\gamma_\pm = \frac{\Omega_p^2}{1-\Omega_c}$$

$$\Omega_p = \frac{\omega_p}{\omega}$$

$$\Omega_c = \frac{\omega_c}{\omega},$$

$$p_\pm = \frac{\alpha E_{0\pm}^2}{f_\pm^2}$$

$$\rho_\pm = \frac{r_0 \omega}{c}$$

The quantity $p_\pm$ which is dimensionless and proportional to $E_{0\pm}^2$ represents the dimensionless beam power on a suitably chosen scale. The beam width parameters $f_\pm$ is a function of $\xi_\pm$, here $\xi_\pm = z/k_\pm r_0^2$ is the normalized propagation distance.

RESULTS AND DISCUSSION

Equation (6) is second order nonlinear differential equation which gives evolution of a laser beam during propagation to collisionless magnetized plasma. By subjecting Eq.(6) under critical condition the general power of laser beam $p_\pm$ is replaced by critical power $p_{0\pm}$ therefore R.H.S. of Eq.(6) takes the form

$$\rho_{0\pm}^2 = \frac{24\delta_\pm}{3\gamma_\pm} \frac{e^{p_{0\pm}}}{p_{0\pm}} \quad (7)$$

Where, $p_{0\pm} = \alpha E_{0\pm}^2$. The above equation represents equation of critical curve which facilitates two regions the region above critical curve corresponds to self-focusing region whereas the region below the critical curve gives the defocusing of laser beam.

Henceforth following investigation is restricted only for extraordinary mode. For extraordinary mode Eq. (7) takes the form,

$$\rho_{0+}^2 = \frac{24\delta_+}{3\gamma_+} \frac{e^{p_{0+}}}{p_{0+}} \quad (8)$$

From Fig. 1 (a) it is seen that initially with increase in value of critical beam power critical beam radius decreases and attains constant value at $p_{0+}=1$ with further increase in critical beam power critical beam radius increases. Additionally with increase in Ω_c the critical curve shifts downwards.

Fig 1 (b). shows self-focusing of Gaussian laser beam with different values of Ω_c. From Fig. 1 (b) oscillatory self-focusing is observed. Additionally with increase in value of Ω_c the periodicity in self-focusing length decreases. Again from Fig. 1 (b) it is seen that with increase in value of Ω_c the minimum of beam with parameter f_+ decreases which indicates the strong self-focusing of Gaussian laser beam with increase in value of Ω_c.

CONCLUSION :

The above investigation shows that pre-conditioning of a critical curve in the begining of propagation can determine propagation dynamics effectively. From analytical study it is conclude that stronger self-focusing of Gaussian laser beam can be obtain with increase in value of.

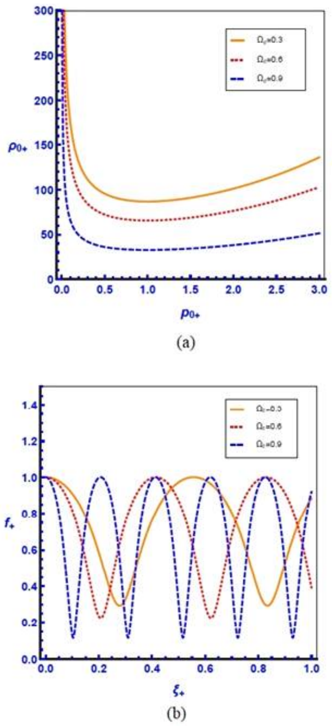

Fig. 1 (a) Critical curves for various b values, (b) Dependence of the extraordinary beam-width parameter f_+ on the dimensionless propagation distance ξ_+.

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