EFFECTS OF LARMOR RADIUS ON INVERSE FREE ELECTRON LASER ACCELERATOR WITH STAGGERED UNDULATOR

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Abstract

In this paper, the theory of inverse free electron laser (IFEL) accelerator using staggered undulator has been discussed. The important contribution of staggered undulator parameter and the finite Larmor radius effect on energy saturation, saturation length and accelerating gradient of the IFEL accelerator are included in the analysis. Considering the synchrotron radiation losses, the IFEL accelerator equations are derived.

INTRODUCTION

The inverse free electron laser (IFEL) accelerator is the most advance laser based accelerator scheme. It has been demonstrated that the accelerating gradient is significantly larger than what we achieve with conventional IF accelerator. In the IFEL accelerator the energy transfer is from the laser beam to electrons. In an IFEL relativistic particles are moving through an undulator magnetic field with an electromagnetic wave propagating parallel to the beam. The undulator magnets produces a wiggling motion in a direction parallel to the electric vector of the laser. Hence energy is transferred from wave to the particle, if the resonance condition $\lambda = \frac{\lambda_u}{2\gamma^2}(1+K^2)$ satisfies. Where λ is laser wavelength, λ_u is the undulator wavelength, $K = \frac{eB_0\lambda_u}{2\pi mc^2}$ is the undulator parameter. As the particle gain energy, the resonance condition of the free electron laser cannot be maintained for a long distance. The resonance condition can be maintained in two ways, firstly by changing the undulator period and secondly by changing the magnetic field of the undulator.

INVERSE FREE ELECTRON LASER ACCELERATOR EQUATIONS

The equation describing the motion of the electrons in the IFEL can be derived from the Lorentz equation of motion

$$\frac{d\vec{\beta}}{dt} = \frac{e}{\gamma m_e c}\left[\vec{E}_L + \vec{\beta}\times\left(\vec{B}_L + \vec{B}\right)\right]$$

Magnetic field of a staggered array undulator with an axial magnetic field produced by a solenoid

$$\vec{B}_s = \left[0, B_u\left(\sin\pi f/\pi f\right)\sin k_u z, B_0\right]$$

The electromagnetic wave propagating along the undulator is described by

$$\vec{E}_L = \left[E_0\sin\psi, E_0\cos\psi, 0\right] \qquad \vec{B}_L = \left[E_0\cos\psi, E_0\sin\psi, 0\right]$$

The electron velocity is given by

$$\beta_x = \frac{\tilde{K}}{\gamma}\cos(\omega_u t) - \frac{K_L}{\gamma}\cos\psi + \beta_\perp\cos(\omega_u t)$$

$$\beta_y = \beta_\perp\sin(\omega_u t) \qquad \beta_z = \beta^* - \frac{\tilde{K}^2}{4\gamma^2}\cos 2(\omega_u t) - \frac{K_L^2}{4\gamma^2}\cos 2\psi$$

The change in electron energy is given by

$$\frac{d\gamma}{dz} = A\frac{\tilde{K}}{2\gamma}\sin(\xi)\sum_m\left[J_{m-1}(0,\chi) - J_{m+1}(0,\chi)\right]$$

The resonance condition is

$$\omega = \frac{2\gamma^2(\omega_u + \omega_c)}{\left[1 + \frac{\tilde{K}^2}{2} + \gamma^2\beta_\perp^2\right]}$$

Adding the synchrotron radiation losses and using resonance condition. The change in electron energy is given by

$$\frac{d\gamma}{dz} = \tilde{A}\sqrt{\frac{\omega_u + \omega_c}{\omega}}[JJ] - \frac{2}{3}\frac{r_e}{c^2}\gamma^4\left[2\omega_u^2\frac{\omega_u + \omega_c}{\omega} + \beta_\perp^2\omega_c^2\right]$$

The solution is given as

$$\gamma(z) = \gamma_\infty - [\gamma_\infty - \gamma_0]e^{-\frac{4F}{\gamma_\infty}(z - z_0)}$$

RESULT AND DISCUSSION

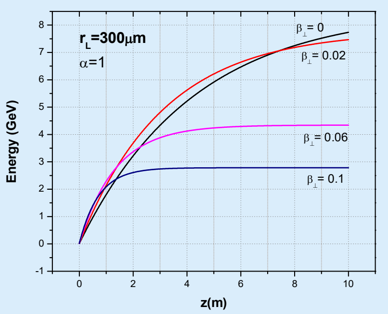

Figure 1: Electron energy vs distance for a fixed undulator wavelength

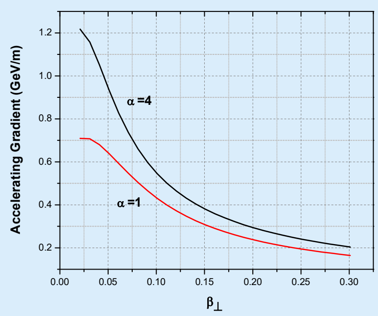

Figure 2: Accelerating gradient vs $\beta_\perp$

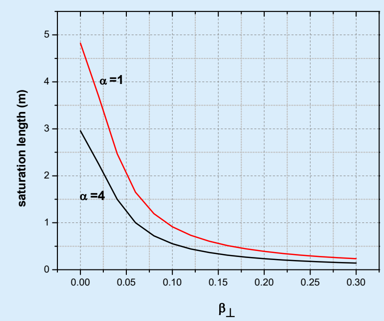

Figure 3: Saturation length vs $\beta_\perp$

REFERENCES

[1] R.B. Palmer, J. Appl. Phys., 1972, 43, 3014.
[2] E.D. Courant, C. Pellegrini and W. Zakowicz, Phy. Rev. A, 1985, 32, 5.
[3] J. Duris, P. Musumeci, et.al. Nature Communications 5, 4928, 2014
[4] J.P. Duris, P. Musumeci and R.K.Li, Phys Rev. ST Accel. Beams 15, 061301 (2012).
[5] Roma Khullar, G. Mishra, *J. Synchrotron Rad.* (2018). 25, 1623-1626.
[6] Roma Khullar, G. Mishra, *IEEE Transaction on Plasma Science*, vol. 49, no. 2, 2021.
[7] S.G. Anderson, G.G. Anderson et al, Proceeding of 2011 Particle Accelerator Conference, NY, p.331.
[8] A. Tremainc et.al. Proceeding of 2011 Particle Accelerator Conference, NY, p.1.
[9] C. Sung, S. Ya. Tochitsky, S. Richie, J. B. Rosenzweig, C. Pelligrini, C. Joshi, Phys Rev. ST Accel. Beams 9,120703 (2006).
[10] G. Mishra, Avni Sharma, *Trans. On Plasma Sci.,* 50 (12), 4854-4859, 2022.