Title

Review of Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression in Free-Electron Lasers

Author
Perez, Juan

Publication Date
2023-12-11

Review of Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression in Free-Electron Lasers

Juan Perez[1]

[1]*Electrical and Computer Engineering Department, University of California – Los Angeles, 420 Westwood Plaza, Los Angeles, CA 90095 USA*
juanperez13@g.ucla.edu

Abstract: A laser heater utilizing a traditional Gaussian transverse laser mode is converted into a Laguerre-Gaussian 01 (LG_{01}) transverse mode through use of a spiral phase plate to observe its greater suppression of microbunching instability (MBI).

INTRODUCTION

Radiation properties of free-electron lasers (FELs) make it a powerful tool within the medical field, condensed matter physics, materials science, etc. However, a high quality electron beam (e-beam) with high brightness and high current can have its quality slashed due to the effects of microbunching instability (MBI). To counteract this, a laser heater (LH) can be employed to mitigate MBI accumulation by increasing energy spread of the e-beam resulting in greater FEL intensity by a factor of 3[1].

The LH at Linac Coherent Light Source (LCLS) utilized a transverse Gaussian-shaped laser matched to transverse e-beam shape which in optimal conditions could provide an energy distribution of a parabolic shape, however, to account for jitter, these conditions can't be obtained resulting in double-horn energy distributions[1]. Thus, Laguerre-Gaussian modes are looked to because of their circular and radial symmetry in the transverse plane[2]. A Laguerre-Gaussian 01 (LG_{01}) mode, donut-like profile, in particular offers a Gaussian-shaped energy distribution resulting in an exponential suppression of MBI. The effects of this and how to produce these donut-shaped intensity beams will be outlined in the following sections.

METHODS

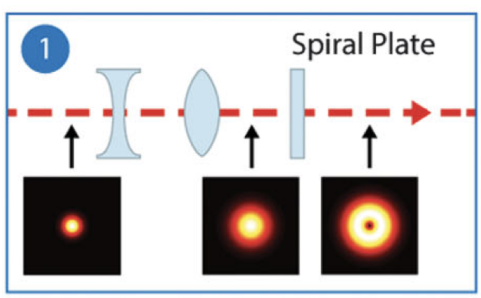

Fig. 1. Spiral Phase Plate (Ref. [1], inset 1 of Fig. 1).

The LH transverse profile first passes through a concave and convex lens combination in order to adjust the beam size of the incident FEL. The Gaussian profile then passes through a spiral phase plate (SPP) which writes an increasing spiral phase onto the beam for a total phase change of 2π and generates a null in the field amplitude at the center of the laser resulting in a donut-like intensity profile[1]. This results in the LH having a LG_{01} transverse mode allowing for analysis of its effects on MBI. The beam then passes through a 135 MeV spectrometer in Dogleg DL1 for analysis of the energy distributions.

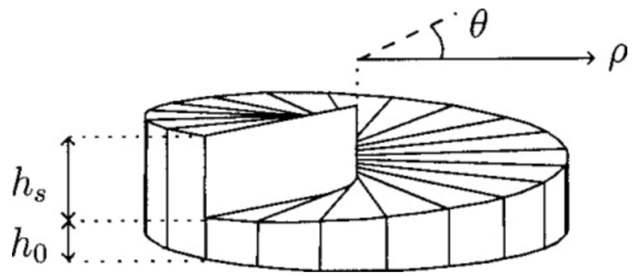

Fig. 2. Spiral Phase Plate Sketch (Ref. [3], Fig. 1).

However, the SPP must be designed properly to ensure the correct mode is acquired by imposing an azimuth-dependent retardation on the optical field[3].

$$\phi(\theta, \lambda) = \frac{2\pi}{\lambda}\left[\frac{(n-n_0)h_s\theta}{2\pi} + nh_0\right] \quad (1)$$

Equation (1) informs us of the azimuth-dependent optical phase delay. Utilizing this, the SPP can be properly designed to create the LG_{01} transverse mode from the initial Gaussian mode. There are multiple different factors to be taken into consideration such as n, the refractive index of the plate, n_0, refractive index of the surrounding medium, and λ, the wavelength of the incident light. Optimizing these parameters correctly will result in a SPP that can properly convert a Gaussian profile to an LG_{01} profile.

RESULTS AND INTERPRETATION

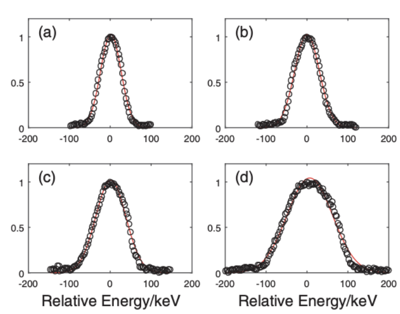

Fig. 3. LG_{01} Energy Distributions (Ref. [1], Fig. 2).

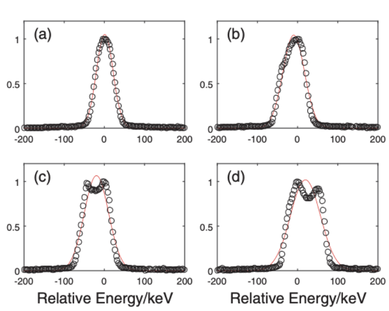

Fig. 4. Gaussian Energy Distributions(Ref. [1], Fig. 3).

The 135 MeV spectrometer was utilized to gather energy distributions of the LH for both the LG_{01} transverse mode and Gaussian transverse mode at different laser energies. Figure 3 illustrates how the gaussian shape is preserved for a large range of energies with 3(a) showing the distribution for an energy of 25.1 keV and 3(d) showing the distribution for an energy of 55.7 keV. Observing Figure 4, we see that 4(b) illustrates the beginnings of a double-horn distribution for an energy of 26.7 keV and 4(c) is more prominent at an energy of 30.1 keV. The LG_{01} transverse mode's ability to retain a gaussian shape at high energies signifies its potential for better microbunching suppression[1]. This allows for the beam to continue to appear as one heated beam rather than two separate unheated cold beams as it was for the gaussian[1]. This information suggests that the LG_{01} transverse mode is a better alternative to the traditional gaussian transverse mode.

CONCLUSIONS

The LG_{01} transverse mode LH induced a Gaussian energy distribution while demonstrating a greater MBI suppression as opposed to its Gaussian counterpart[1]. This allows for better results to be obtained when utilizing FELs allowing for the improvement upon the current LH in use at LCLS. Further experimentation can be conducted to observe the effects of other modes such as Hermite-Gaussian to explore whether they can succeed in areas where other modes falter. It can also be explored if there other methods to generating the LG_{01} transverse profile via other means other than the spiral phase plate that could potentially garner a higher transmission efficiency.

REFERENCES

1. Tang, Jingyi, et al. “Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression in Free Electron Lasers.” Conference on Lasers and Electro-Optics, Mar. 2019, https://doi.org/10.1364/cleo_si.2019.sf3i.2.
2. J.-M. Liu, Principles of Photonics, 1st ed. Cambridge University Press, 2016.
3. S. S. R. Oemrawsingh, et al. "Production and characterization of spiral phase plates for optical wavelengths," Appl. Opt. 43, 688-694 (2004)