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Author
Nguyen, Joe Duy

Publication Date
2022-12-08

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

Joe Nguyen

Henry Samueli School of Engineering, Department of Electrical and Computer Engineering
University of California, Los Angeles
joenguyen@ucla.edu

Abstract. **–** Free-electron lasers provide accurate angstrom-level wavelength depths yet fall short in their unstable electron beam intensity. In turn, energy spread increases, affecting particle accelerators' quality. We will investigate the significance of laser heaters in microbunching instability suppression using an LG_{01} transverse laser mode.

Introduction.

Laser heaters can optimize microbunching instability (MBI) suppression through controlling both the induced energy spread and the transverse shape of its pulse. Microbunching instability is caused by shot noise and longitudinal charge, leading to energy spreads that damage free-electron lasers. In adding a laser heater, energy spread of the electron beam is increased while remaining under the laser's tolerance levels. The result is an increased intensity with minimal degrading. Currently, the traditional Gaussian transverse laser mode is the standard LH in most FEL facilities to suppress MBI. The distribution is adjusted to accommodate for the induced energy spread, forming a parabolic shape when comparing relative energy to its Gaussian fitting.

However, there is recent theoretical evidence of the transverse Laguerre-Guassian 01 (LG_{01}) mode being more effective in producing a Gaussian distribution, thereby suppressing it in greater quantities. At higher induced energy spread, the aforementioned parabolic shape should remain consistent. The distribution should resemble the standard LH in its Gaussian-shaped induced energy distribution all the while improving microbunching suppression.

The fundamental transverse laser beam mode, the Gaussian mode, is of the lowest order providing the most stability with minimum uncertainty. In turn, it has the lowest dispersion which results in the aforementioned weaker MBI suppression. Studies have been conducted to explore potentially more efficient laser distributions, namely Laguerre-Gaussian modes. Unlike their Gaussian and Hermite-Gaussian counterparts, LG modes have circular and radial symmetry which appear to help FEL perform exponentially better.

Methods.

The MBI suppression can be quantified through identifying the microbunching gain [3]

$$G = \left| \frac{b_f}{b_0} \right| = \frac{I_0}{\gamma I_A} \left| k_f R_{56} \int_0^L ds \frac{4\pi Z(k_0; s)}{Z_0} \right| S_L(k_f) \tag{1}$$

The suppression factor and final energy spread are analyzed in this case of upstream impedance. The microbunching gain is measured as a ratio of final and initial bunching values, giving way to the comparison between the Gaussian mode laser heater and the LG_{01} mode laser heater. The result of measuring the transverse distributions finds that LG_{01} forms a laser size twice as large as that of the Gaussian mode with respect to their electron beam sizes [3]. As such, the final energy spread is further reduced with the LG_{01} mode laser heater.

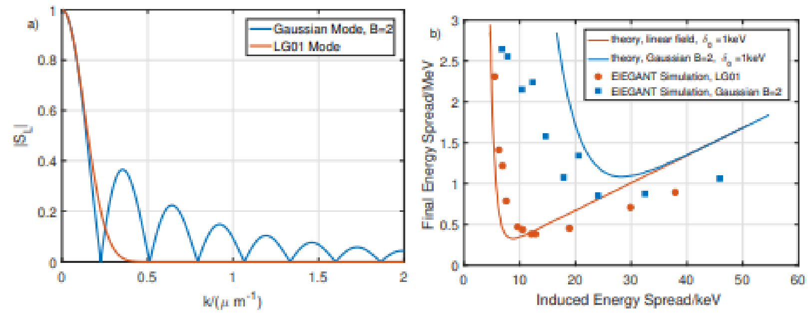

Fig. 1. Simulation of (a) Suppression factor at fixed induced energy spread (b) Final energy spread and ELEGANT simulation of transverse modes [3]

Results and Interpretation.

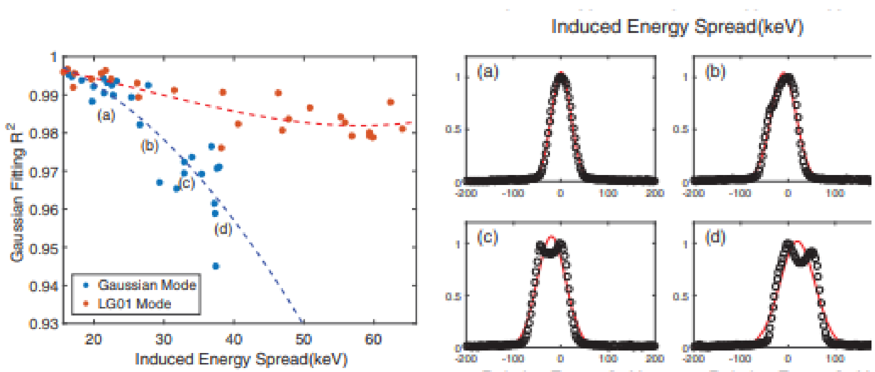

Fig. 2. Gaussian fitting R^2 of induced energy spread. Gaussian fittings of energy distribution at varying energy spreads [2].

As the energy spread increases, the LG_{01} mode retains a clearer Gaussian fitting with a consistent coefficient of correlation R^2. Figures 2(a)-2(d) presents the less stable distribution at the 30-40 keV range, highlighting the shortcomings of the traditional Gaussian transverse mode. However, LG_{01} mode is susceptible to a 1% decrease in its fitting due to laser transverse jitter. Overlapping of the e-beam may occur in the center of the laser, resulting in inconsistent fittings and thereby potentially lower MBI suppression similar to that of figures 2(c) and 2(d). Nonetheless, the LG_{01} mode continues to prove exponentially steadier with increasing induced energy spread.

Conclusions.

The LG_{01} LH provides greater benefits in suppressing MBI in free-electron lasers than its traditional Gaussian LH counterpart. Introducing this transverse laser mode to LCLS and other FEL facilities can help reduce the degradation of e-beam quality and overall particle accelerator costs. Additional modes not only pertaining to LG and Gaussian but Hermite-Gaussian modes as well should be explored in the future to best optimize FELs.

References

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