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Comparison of Laguerre-Gaussian Mode and Perfect Vortex Beam Laser Heaters for Microbunching Instability Suppression in Free-Electron Lasers

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Abstract: Microbunching instability (MBI) in X-ray free-electron lasers (XFELs) is a primary parasitic effect by which initial perturbations in the electron beam are amplified and degrade the quality of the output radiation. In this paper we expand upon MBI suppression in XFELs through the use of a Laguerre-Gaussian 01 (LG_{01}) mode laser heater to introduce an initial energy spread to prevent downstream MBI. We analyze the benefits of the LG_{01} mode and provide an analysis of a perfect vortex beam (PVB) laser heater as an alternative.

INTRODUCTION

X-ray free-electron lasers (XFELs) are a cutting edge technology which produce coherent light at ultra-short wavelengths, naturally finding direct applications in chemistry and biomedical imaging where they can extract detailed images of dynamically occurring processes. XFELs operate by accelerating a beam of electrons through alternating magnetic fields in order to produce highly intense, coherent x-ray radiation. However as the beam propagates, dense bunches of electrons can form and produce coherent radiation that will interact with the accelerator structure. This phenomenon is referred to as microbunching instability, and it causes a positive feedback loop which will amplify the size and density of the bunch and lead to degraded beam quality. By modulating the electron beam with a co-propagating laser beam, we can exploit the phenomenon of Landau damping to induce an initial energy spread in the electron beam which will prevent runaway MBI accumulation downstream. In this paper we confirm the effective suppression of MBI via an LG_{01} laser heater provided by Tang et al. and explore an alternative application of a PVB laser-heater with the focus of increasing resilience to transverse jitter.

METHODS

Tang et al. demonstrate the successful implementation of an LG_{01} laser heater in inducing the desired 20-30 keV energy spread, but observe the undesirable effect of a double-horn shape in the relative energy distribution of the electron beam due to transverse jitter. The LG_{01} mode has a central null, from which the electric field increases linearly radially outward. As a result, electrons closer to the center of the beam receive less energy modulation compared to those further out, which preserves the Gaussian profile of the electron beam. The profile of the LG_{01} mode makes it particularly susceptible to transverse jitter effects, where the energy spread induced in the electron beam can vary drastically depending on the beam's overlapping with the central null or overlapping with the outer annular intensity maximum.

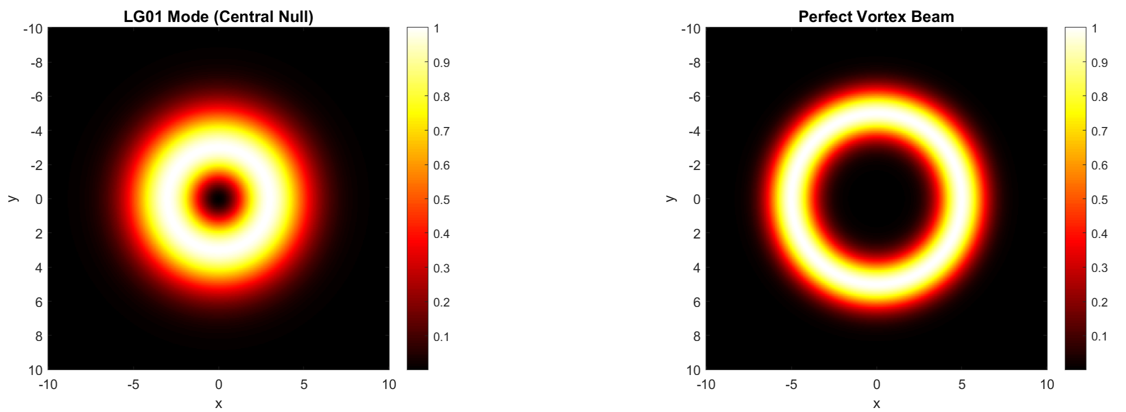
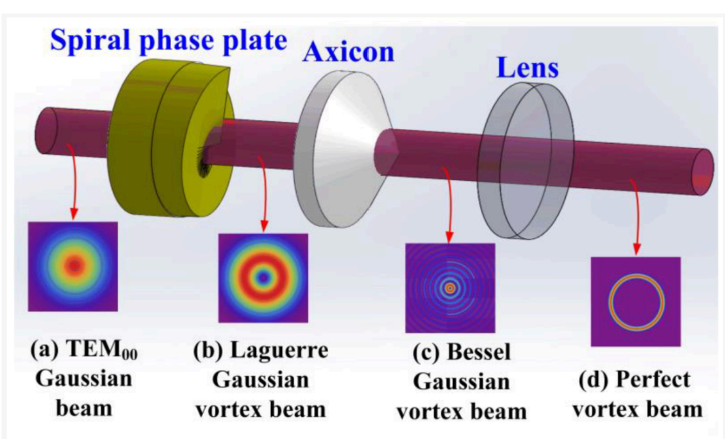


Fig. 1. Transverse profile of an LG_{01} beam (left) compared to that of a PVB (right), where the color bar represents intensity. We see that the vortex beam can be tuned to a much wider central null.

We can adjust the width of the central null of the PVB to be comparable to the electron beam in order to decrease the sensitivity to transverse jitter, although we need to ensure that the electron beam still interacts with the rings sufficiently. We refer to Tao et al. for the practical implementation of yielding a perfect vortex beam from the Gaussian beam laser heater already installed at LCLS.



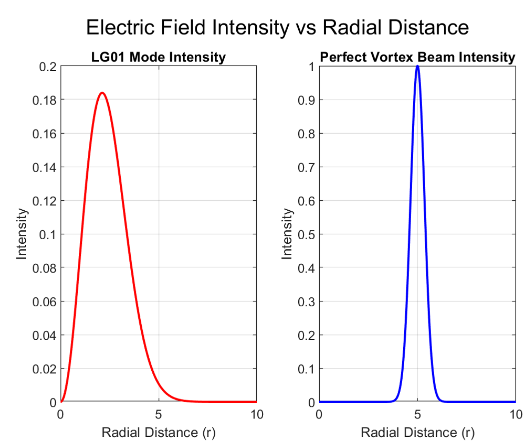


Fig 2. Left: Schematic diagram for the optical system that can convert the existing TEM_{00} laser heater into a perfect vortex beam with control over the ring radius and width. Right: Comparison of electric field profiles for PVB and LG_{01} modes.

RESULTS AND INTERPRETATION

The implementation of a PVB will allow us to take advantage of a much wider null region without a steep gradient in the electric field, giving more even energy modulation to the electron beam. However, since the central null of the beam does not have any electric field amplitude within it, the induced energy spread will be much less than that of the LG_{01} laser heater.

CONCLUSION

The implementation of a PVB in place of a LG_{01} laser heater will allow us to purchase resilience to transverse jitter due to the uniformity of the electric field within the central null region, at the cost of imparting a much smaller energy spread, which may be smaller than the 20-30 keV. This means that we would not be reaching the threshold for ideal MBI suppression, which would require us to deliver more power to the laser heater to achieve an ideal induced energy spread. This application is best in cases where transverse jitter is a dominating side-effect that degrades the increased MBI suppression of an LG_{01} mode significantly, and where power provided to the laser heater is not a tight specification.

REFERENCES

1. Tang J, Lemons R, Liu W, Vetter S, Maxwell T, Decker FJ, Lutman A, Krzywinski J, Marcus G, Moeller S, Huang Z, Ratner D, Carbajo S. Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression in Free-Electron Lasers. Phys Rev Lett. 2020 Apr 3;124(13):134801.
2. Tao X, Liang Y, Zhang S, Li Y, Guo M, Li P. Generation of Perfect Vortex Beams with Complete Control over the Ring Radius and Ring Width. *Photonics*. 2023; 10(12):1382.