Title

Mode Conversion from Gaussian to LaguerreGaussian (LG01) using the Spiral Phase Plate (SPP) Method

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Mode Conversion from Gaussian to Laguerre-Gaussian (LG01) using the Spiral Phase Plate (SPP) Method

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Abstract: The focus of this paper will be on understanding how the SPP contributes to the generation of a Laguerre-Gaussian mode from a Hermite-Gaussian mode and its role in suppressing microbunching instability (MBI), thereby enhancing free-electron laser capabilities.

INTRODUCTION

In recent advancements within the realm of free-electron lasers (FELs) and beam stability in storage rings and Linacs, the utilization of innovative techniques for shaping laser beams has proven instrumental. Notably, the MBI suppression shown in the Laguerre-Gaussian (LG) transverse mode compared to the Hermite-Gaussian mode significantly showed its effectiveness to maintain its gaussian shape energy distribution over the Gaussian mode which resulted in the undesirable double horn distribution [1]. However, to first attain this Laguerre-Gaussian mode, a mode conversion method had to be chosen and it's what we'll be elaborating on in this paper.

This mode conversion known as the spiral phase plate was chosen due to its >95% transmission efficiency and ease of replication process producing identical plates [1, 3]. With this ease of replication process and high efficiency you could combine any number of Spiral Phase Plates to achieve your desired topological charge [3, 5]. In the research article [1] the desired mode was the LG01 corresponding to an azimuthal mode number of 1 [2]. This azimuthal mode number corresponds to the number of twists produced in the helical wavefront [5].

This donut shaped LG light beam caused by the SPP results in a helical wavefront, which is a characteristic of optical vortex beams that carry orbital angular momentum (OAM) [4, 6]. The phase modulation induced by the spiral phase plate controls the distribution of this angular momentum. The SPP facilitates the generation of such complex optical modes by manipulating the phase of the incident light in a controlled manner.

Manipulating the phase of the incident light is the method we are going to focus on in this paper to analyze the effects of our spiral phase plate. Specifically, we will be looking into the different affects that different step heights (h_s) pictured in Fig. 1. impose on the LG01 mode [4]. Since the step height is small enough, we remain in the paraxial regime [4].

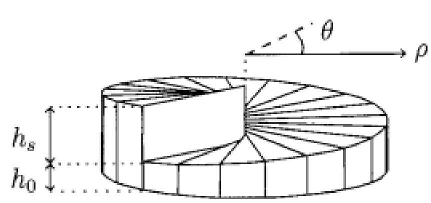

Fig. 1. Sketch of spiral phase plate [3]

METHODS

The other parameters involved in the SPP, like the azimuthal angle, increases as the physical spiral plate begins to grow in thickness. This means while we adjust the height step parameter other parameters will adjust themselves to what we set the step height to be. We denote the step height equation to be:

$$Q = \frac{h_s(n - n_0)}{\lambda}$$

Where Q is the topological charge, h_s is the step height, n, n_0, are the refractive indices, and λ is the wavelength [3]. We shall keep all parameters constant except the step height to see its affects. In the graph below was generated in MATLAB, we chose the values h_s to be 0.1mm, 0.5mm, and 1.0mm.

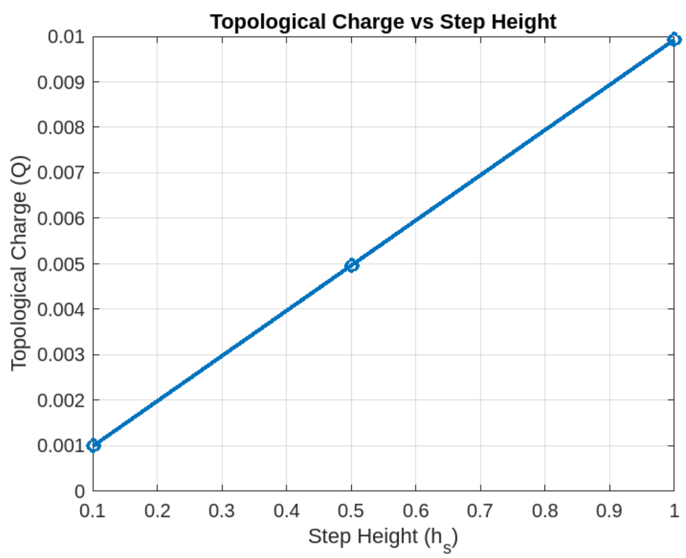

Fig. 2. h_s values for 0.1mm, 0.5mm, and 1.0mm [8]

Similarly in research article [5] they found the increase in topological charge is proportional to the increase in step height as seen in the image below:

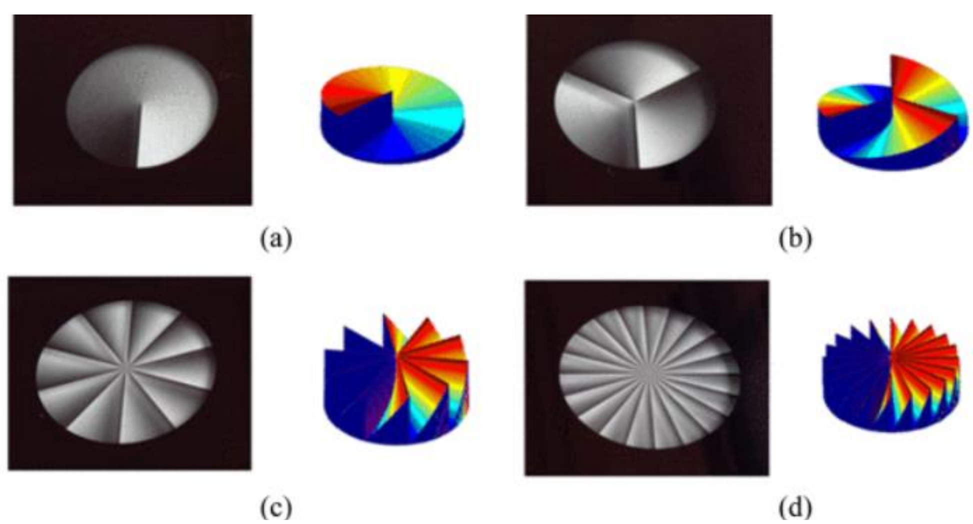

Fig. 3. Amount of helical twists as topological charge changes [5]

RESULTS AND INTERPRETATION

Investigating more into how the spiral phase plate converts from a Hermite-Gaussian to a Laguerre-Gaussian 01, we can clearly see correlations between the topological charge, number of helical twists, and the step height of the plate. We can see that the topological charge is directly proportional to the step height in Fig. 2. As the step height increases so does the topological charge. Similarly, as the topological charge increases so does the number of helical twists in the wavefront.

The OAM that's generated by the SPP is also said to be $l\hbar$ per photon where l is the azimuthal mode number or topological charge and $\hbar$ is plank's constant [7]. This is known as the angular momentum and is given by [7]:

$$J_z = l\hbar$$

This could also be connected to the value of step height, since step height is proportional to topological charge and azimuthal mode number is the same value as topological charge. Meaning as the topological charge increases this means there is more angular momentum happening in the helical wavefront that is being produced.

CONCLUSIONS

The main purpose of this paper was to focus on the pivotal role of the SPP in converting a Hermite-Gaussian mode to a Laguerre-Gaussian 01 mode for MBI suppression in free-electron lasers (FELs). The choice of the SPP is driven by its high transmission efficiency and ease of replication, enabling precise control over the topological charge. The topological charge, directly proportional to the step height, influences the generation of a donut-shaped Laguerre-Gaussian (LG) light beam, characterized by a helical wavefront with orbital angular momentum. The research explores the correlation between the step height, topological charge, and the number of helical twists. As the step height increases, both the topological charge and the number of twists in the wavefront rise. The angular momentum generated by the SPP, quantified as $l\hbar$ per photon, further highlights the significance of the topological charge and, by extension, the step height. This comprehensive analysis sheds light on the intricate relationship between SPP parameters and the resulting optical modes, offering valuable insights for advancements in FELs and beam stability.

REFERENCES

1. Tang, J., Lemons, R., Liu, W., Vetter, S., Maxwell, T., Decker, F. J., ... & Carbajo, S. (2020). Laguerre-gaussian mode laser heater for microbunching instability suppression in free-electron lasers. *Physical review letters*, *124*(13), 134801.

2. Allen, Les, et al. "Orbital angular momentum of light and the transformation of Laguerre-Gaussian laser modes." *Physical review A* 45.11 (1992): 8185.

3. Oemrawsingh, S. S. R., Van Houwelingen, J. A. W., Eliel, E. R., Woerdman, J. P., Verstegen, E. J. K., & Kloosterboer, J. G. (2004). Production and characterization of spiral phase plates for optical wavelengths. *Applied optics*, *43*(3), 688-694.

4. Beijersbergen, M. W., Coerwinkel, R. P. C., Kristensen, M., & Woerdman, J. P. (1994). Helical-wavefront laser beams produced with a spiral phaseplate. *Optics communications*, *112*(5-6), 321-327.

5. Wang, J., Cao, A., Zhang, M., Pang, H., Hu, S., Fu, Y., ... & Deng, Q. (2016). Study of characteristics of vortex beam produced by fabricated spiral phase plates. *IEEE photonics Journal*, *8*(2), 1-9.

6. Leach, J., Padgett, M. J., Barnett, S. M., Franke-Arnold, S., & Courtial, J. (2002). Measuring the orbital angular momentum of a single photon. *Physical review letters*, *88*(25), 257901.

7. O'neil, A. T., MacVicar, I., Allen, L., & Padgett, M. J. (2002). Intrinsic and extrinsic nature of the orbital angular momentum of a light beam. *Physical review letters*, *88*(5), 053601.

8. GonzalezLaura. (n.d). *Github – laura-gonzalez412/170A-code https://github.com/laura-gonzalez412/170A-Code/tree/6f2cc17e218b7f0c73409a4b01eb4b0da123cede*