Title

Review of the Laguerre-Gaussian Mode Conversion Process

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Review of the Laguerre-Gaussian Mode Conversion Process

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Abstract: This review examines the author's solution to the FEL MBI problem where the quality of the FEL laser is diminished. A proposed solution is using an LG_01 configuration instead of the traditional Gaussian in the laser heater to suppress the effects of the Microbunching intensity phenomenon.

INTRODUCTION

FEL lasers are used in various practical applications such as research in materials science, chemical technology, biophysical science, medical applications, surface studies, and solid-state physics as well as potential future applications ranging from industrial processing of materials to light sources for soft and hard x-rays. [1] In some of the applications, having a quality e-beam is of high interest. To achieve this, suppressing the occurrence of MBI is crucial.

METHODS

One effective method used by the researchers to change the original Gaussian mode to a transverse Laguerre-Gaussian 01 by adding spiral phase plates. When the IR laser goes through these spiral phase plates it writes onto the electron beam an increasing spiral phase resulting in a total phase change of 2pi. Phase plates are used heavily in photonics applications to convert between different polarizations of light. Other examples being quarter-wave plates, half-wave plates, and utilization of plates in a Fabry Perot cavity. [2]

This method of mode conversion work by introducing a helical phase pattern across the wavefront of a light beam, resulting in the generation of optical vortices with orbital angular momentum. These devices are valuable tools for manipulating the spatial properties of light [3]

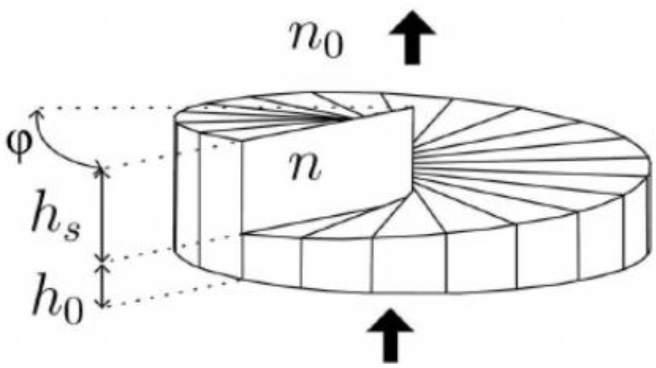

Figure 2: Schematic of a spiral phase plate with a step index of q = $h_s(n-n_0) / \lambda$, where H_s is step height, n and n_0 are refractive indices of the SPP and surrounding medium respectively, and λ is the wavelength of the incident light [4].

A Spiral Phase Plate (SPP) is a transparent plate of some refractive index n, with a thickness proportional to the azimuthal angle ϕ

$$h = h_s \frac{\varphi}{2\pi} + h_0 \tag{1}$$

where h_s is the step height and h_0 the base height of the device (1). When inserted into the waist of a Gaussian beam, with a plane phase distribution, it imprints a vortex charge (2).

$$q = \frac{h_s(n - n_0)}{\lambda} \tag{2}$$

When a Gaussian beam is diffracted off such an SPP, the resulting mode can be viewed as a superposition of LG modes [4]. To give an idea of the scale of these quantities, sample calculations are provided below.

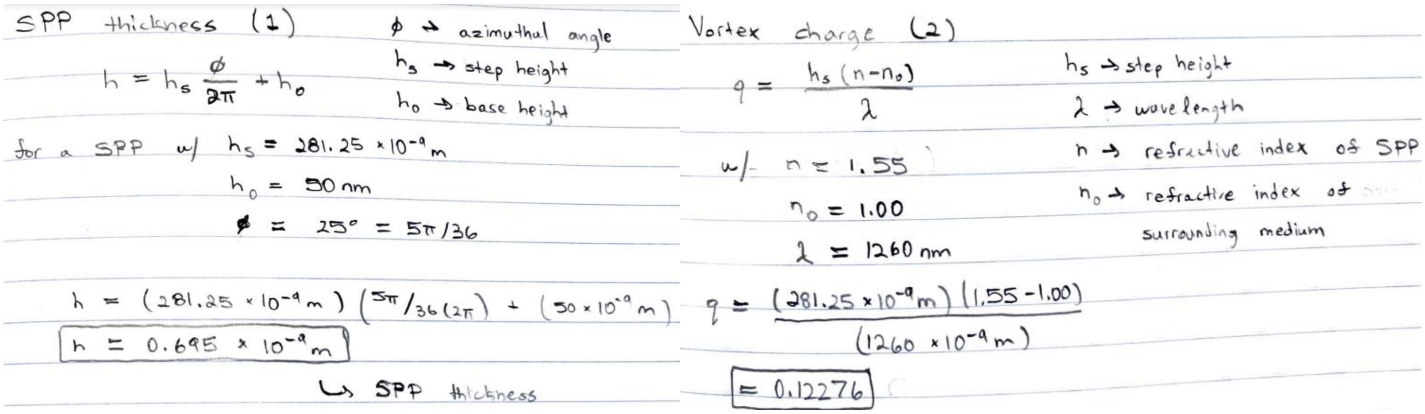

Figure 2: Hand calculations of equations (1) and (2)

In this particular application, the SPP used was as a diffractive optic with 16 steps, each with an increasing thickness arranged circumferentially around the plate resembling a spiral staircase only effecting the phase structure around the beam [5].

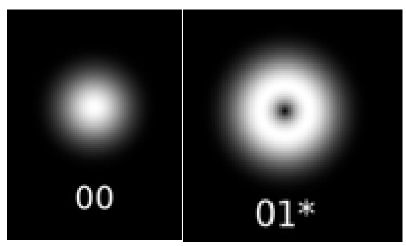

Figure 3: Intensity distribution for modes before and after conversion. [6]

Belows is a simplified schematic drawing of the optical mode conversion from the supplemental paper, with two Galilean telescopes strategically oriented specific distances before and after the spiral phase plate. This was done to optimize effciency in the mode conversion. [5]

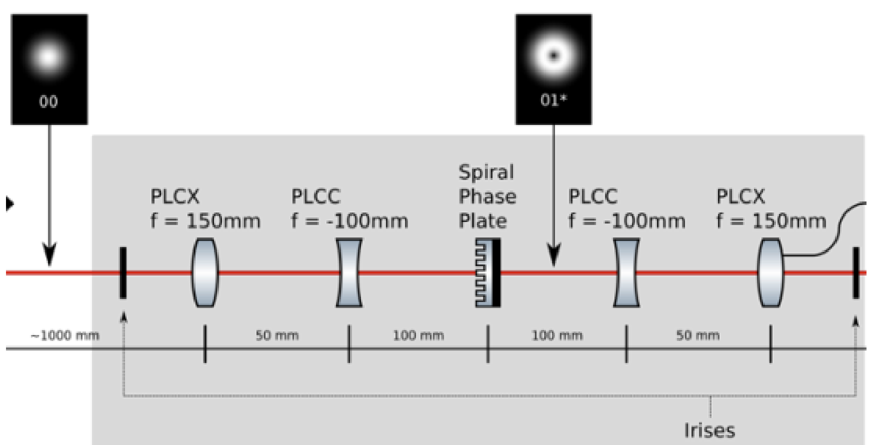

Figure 4: Simplified optical mode-conversion and schematic [5]

RESULTS AND INTERPRETATIONS

Overall, the use of a spiral phase plate in mode conversion to a Laguerre-Gaussian was crucial towards suppressing the microbunching instability phenomenon observed in free electron lasers. The LG_01 mode was able to retain the desired Gaussian fitting at relatively low and high laser power. [7]

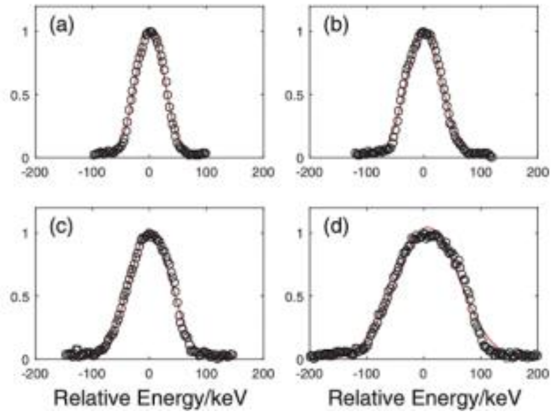

Figure 5: Slice energy spread of the e beam after the laser heater as a function of LG01 laser energy. Total energy spread measured at 135 MeV spectrometer is fitted by the black line. The initial energy spread (with laser heater off) is removed in quadrature to obtain the red dashed line and the circles. (a)–(d) Four examples of energy distributions with (a) 25.1, (b) 30.3, (c) 36.8, and (d) 55.7 keV rms energy spread and their corresponding Gaussian fits.

Another indicator of superior microbunching instability suppression was a lower spectral signal contribution signifying a reduction in MBI. This metric was measured by using a midinfrared (MIR) spectrometer enabling the characterization of the microbunching profile of the electron beam. In the figure below the LG_{01} showcased better suppression especially in the 15 to 20 keV energy spread range.

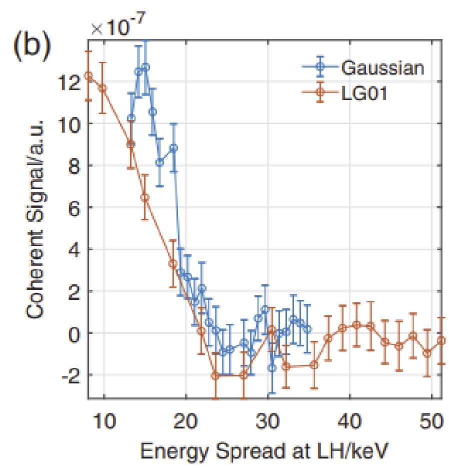

Figure 6: (b) integrated MIR spectral intensity for k ∈ ð3000; 5000Þ cm−1 as a function of induced energy spread by both the LG01 and Gaussian mode LHs [7].

CONCLUSIONS

The authors were able to demonstrate greater efficiency in reducing microbunching instability through their optical conversion method. By changing from the routine Gaussian laser heater to a LG_01 they were able to induce a Gaussian energy distribution. Use of the spiral phase plate in mode conversion, proved to be a high efficiency method with a reported 95% transmission efficiency and achievement of sufficient laser energy to induce energy spreads at optimal levels.

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