Title

A Review on Using Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression

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A Review on Using Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression

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Abstract: Microbunching instability (MBI) is a phenomenon in photonics known to generate beam loss and degrade beam quality. Here, this review discusses the optical properties of LG_{01} transverse laser mode and its effectiveness in MBI suppression.

INTRODUCTION

Microbunching instability (MBI) is a beam challenge detrimental to high brightness particle accelerators and light sources such as linacs and free-electron lasers (FELs) respectively. The proposed experiment of MBI suppression uses a transverse Laguerre-Gaussian 01 (LG_{01}) laser mode and compares its improved effectiveness to traditional Gaussian transverse laser mode [1]. The effects of implementing MBI suppression can be decomposed by downstream measurements such as longitudinal phase space analysis and coherent radiation spectroscopy.

MBI suppression can be created with a laser heater (LH) that utilizes an undulator in a propagating infrared (IR) light to modulate and increase energy spread of the *e*-beam without exceeding the tolerances of the FEL. A greater amount and distribution of energy spread would reduce the downstream MBI accumulation. The Gaussian-shaped energy distribution generated by the transverse LG_{01} mode expectedly results in the exponential suppression for microbunching gain. Ultimately, the paper continues to summarize the influence of LG_{01} mode lasers on MBI suppression and FEL performances.

One element of the paper seen in the principles of photonics and in class is the Gaussian modes. Similar to plane waves, Gaussian modes are normal modes of wave propagation in homogeneous isotropic mediums. LG_{01} mode is just one of the mode fields that uphold a specific form depending on the transverse coordinates of symmetry [2]. While Hermite-Gaussian functions are in the rectilinear coordinates, Laguerre-Gaussian functions are in the cylindrical coordinates which lead to its circular and radial symmetry in the transverse plane.

The paper dives into LH spatial shaping in Soft x-ray self-seeded (SXRSS) FEL emission which is quintessential for photon-hungry spectroscopies that demands precise selection of several elementary excitations. [3] Beyond what the paper details, the principle of photonics discussed in class sheds light on many parameters and restrictions that the Gaussian beam has which includes the minimum Gaussian beam spot size (w_0), Rayleigh range, propagation constant , confocal parameter, and divergence angle [2]. Meeting such criterias and conditions will allow for the Gaussian beam to remain well collimated and achieve strong longitudinal energy transfer which is desirable for the target of the paper.

METHODS

The schematic for the experimental configuration consists of a layout from the photoinjector to the SXRSS diagnostic end station. The LH Gaussian transverse profile was converted to a LG_{01} distribution from the spiral phase plate (SPP) of the setup that creates a total phase change of 2π. The power of the LG_{01} mode laser heater must be high enough to induce an adequate amount of energy spread. In the experiments, the SPP enables over 95% transmission efficiency to achieve high laser energy of LG_{01} mode [1]. The sufficient induced energy spreads generated at optimal levels and higher allows for the characterization and analysis of the LG_{01} mode laser compared to routine operations regarding relative laser heater energy (μJ), induced energy spread (keV), and bandwidth (eV).

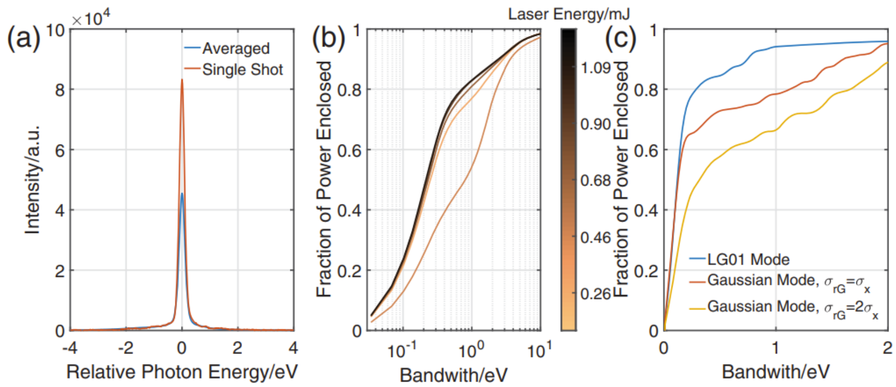

Fig. 1. (a),(b) SXRSS experiment results with LG01 mode LH. (a) Averaged (blue line) and single shot (red line) SXRSS spectra centered at 750 eV photon energy and (b) fraction of SXRSS spectral power as a function of bandwidth for varying LG01 mode energy in the LH. (c) Start-to-end simulation of SXRSS spectral bandwidth with Gaussian and LG01 mode laser heater at undulator length 23.1 m [1].

RESULTS AND INTERPRETATION

In the study of the experiment, the primary outcome focuses on displaying a Guassian-shaped energy distribution induced by LG_{01} mode LH. Optimal MBI suppression is achieved with 20-30 keV induced energy spread. LG_{01} mode laser heater reveals the preservation of a Gaussian-shaped distribution as laser power increases which is consistent with previous measurements analysis.

The Gaussian R^2 fitting coefficient of both modes were compared to quantify the LG_{01} to Gaussian comparison. Effective MBI suppression exhibits significant improvement on numerous FEL operational modes. The root curve fits the induced energy spread well relative to the laser energy and the trickle heating effects at low energy. The improved results of the transverse mode also experienced transverse jitter effects that have detrimental impacts for LG_{01} mode. In fact, the average R^2 of LG_{01} mode decreases approximately 1% from laser transverse jitter as the energy of the mode increases. The new transverse mode laser heater was also found to reduce the sidebands and suppress microbunching altogether.

CONCLUSIONS

Experimenting comparing the LG_{01} transverse mode LH to traditional Gaussian mode LH demonstrates the improvements on MBI suppression. High-efficiency optical mode conversion was achievable from a Gaussian to LG_{01} mode laser beam to induce a sufficient *e*-beam energy spread. The impact of LG_{01} LG is also studied through the metrics of SXRSS performance, monochromaticity, and spectral brightness. These augmentation in mode conversion can be utilized in current and future laser heater designs. For developing the next generation of light sources, future works can take extra steps towards experimenting on different modes of the transverse wave in hopes to ultimately discover further improved results.

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