Title

Validating Microbunching Instability Suppression in Free-Electron Lasers via use of Laguerre-Gaussian Mode Laser Heater

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Validating Microbunching Instability Suppression in Free-Electron Lasers via use of Laguerre-Gaussian Mode Laser Heater

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Abstract: This report aims to affirm the findings presented by Tang, et al. (2020) in their research regarding how Laguerre-Gaussian mode laser heaters are more effective at minimizing microbunching instability in free-electron lasers than the standard Gaussian mode laser heater while also providing another means of producing donut-shaped intensity beams.

INTRODUCTION

A free-electron laser is able to create immensely bright coherent light using free electrons instead of utilizing electronic transitions like in traditional lasers. By using free electrons, FELs are able to emit radiation across a broader spectrum. FELs are important in various scientific and engineering fields such as structural biology, plasma physics, and atmospheric research. A common and potentially detrimental phenomenon that occurs within FELs is microbunching instability (MBI). Due to the effects of longitudinal space charge and synchrotron radiation, MBI arises which causes notable degradation of the electron beam [1].

MBI can be mitigated using a laser heater to increase the spread of energy of the electron beam. A significant part of choosing a laser heater to suppress MBI is also its pulse shape [1]. Tang, et al. found that a Laguerre-Gaussian 01 (LG01) laser mode produced improved results when it came to MBI suppression compared to the traditional Gaussian shaped laser.

METHODS

To induce the LG01 distribution, which is characterized by its donut-shaped intensity profile, a spiral phase plate was utilized in order to impart the necessary phase needed to create the distinctive helical wavefronts of the LG01 mode [3].

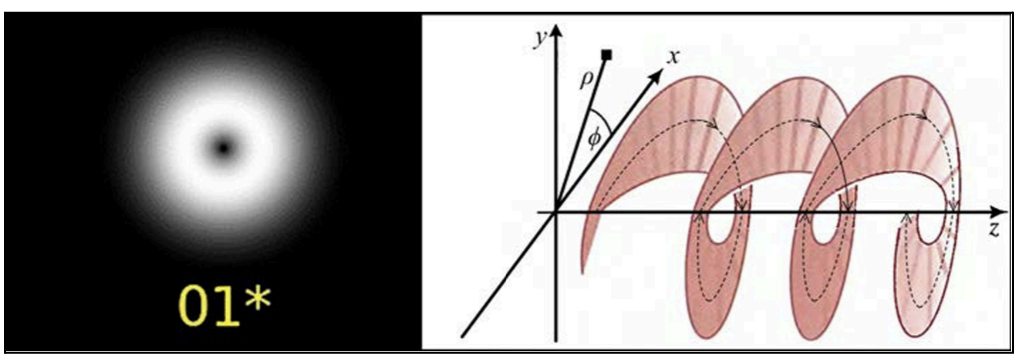

Fig. 1. Intensity Distribution and Wavefront of LG01 Laser Mode (Ref. [2], Fig. 41).

To test if the LG01 proved better than the standard Gaussian at mitigating MBI, a 135 MeV spectrometer was used with a 0.88 m dispersion. By altering the energy provided by an IR laser, the energy distribution width can be changed as well. For data gathering, the electron beam was heated to 65 keV for both Gaussian and LG01 modes to see their performances in MBI suppression while in and out of range of the optimal range of mitigation [1]. With this setup, the following graphs were produced.

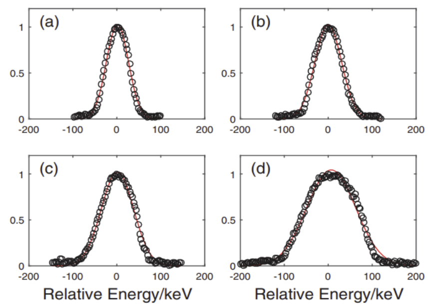

Fig. 2. Energy distributions with (a) 25.1, (b) 30.3, (c) 36.8, and (d) 55.7 keV rms energy spread and their Gaussian fits with LG01 configuration (Ref. [1], Fig. 2).

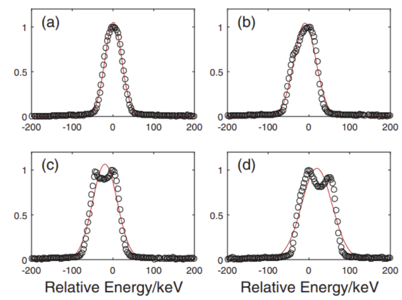

Fig. 3. Energy distributions with (a) 20.5, (b) 26.7, (c) 30.1, and (d) 37.2 keV rms energy spread and their corresponding Gaussian fits with Gaussian configuration (Ref. [1], Fig. 3).

RESULTS AND INTERPRETATION

By analyzing these plots, the conclusion that the LG01 laser mode is better equipped to deal with MBI than standard Gaussian modes can be drawn. As seen in figures 2(a) - 2(d), as the energy spread increases, the LG01 laser mode is able to maintain the Gaussian curve. Conversely in figures 3(a) - 3(d), the Gaussian laser mode reveals a double-horn shape as energy spread rises. This double-horn structure signifies an inferior ability to suppress MBI relative to the LG01 mode since the two horns act as distinct beams which do little to counteract instability and, in turn, results in quality degradation in the electron beam [4].

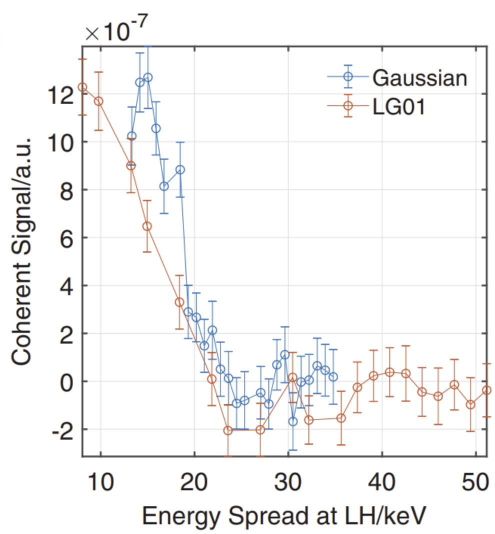

Fig. 4. Spectral intensity as a function of energy distribution for both LG01 and Gaussian modes (Ref. [1], Fig. 4)

Furthermore, with the plots of the spectral intensity of both Gaussian and LG01 Laser Heater modes, the double-horn structure can be clearly seen to occur within the energy spread range of 15 to 20 keV. The energy spread necessary for optimal MBI suppression is around 20 to 30 keV [1]. Since the double-horn structure is just outside this range, this demonstrates how Gaussian laser heaters are significantly worse than LG01 laser heaters at mitigating MBI even outside optimal parameters as the lower the plot is in spectral intensity, the more MBI suppression occurs [1].

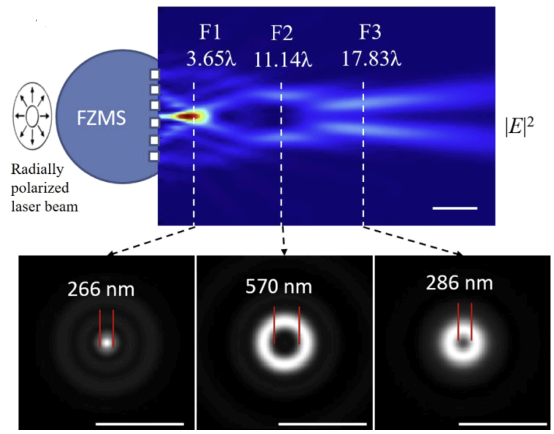

Fig. 5. Double donut beams along optical axis as a result of microsphere (Ref. [5], Fig. 1)

While it can be seen that the LG01 mode is more than adequate to reduce the presence of MBI, it is not the only way to produce donut-shaped intensity beams. For example, engineered microspheres can generate these types of beams. By directing a radially polarized laser beam into the side of the microsphere, a pair of center-hollowed focused donut beams are generated [5].

CONCLUSIONS

It has been recorded that, compared to the traditional Gaussian laser heater, the LG01 mode is superior in terms of minimizing MBI through the analysis of how each mode responds to induced energy spreads. Potentially, these findings can assist in the development of new laser heater designs for FELs [1]. Additionally, there are multiple ways of generating beams with donut-shaped intensity such as with engineered microspheres. Microsphere designs can lead to new micro-optics for light field generation and other applications such as light illumination microscopy [5].

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