Title

Review of Laguerre-Gaussian Mode Laser Heater

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Publication Date

2023-12-10

Review of Laguerre-Gaussian Mode Laser Heater

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Abstract: The paper "Laguerre-Gaussian Mode Laser Heater for Microbunching Instability (MBI) Suppression in Free-Electron Lasers" presents an experimental demonstration of effective MBI suppression using a Laguerre-Gaussian mode laser heater (LG01).

INTRODUCTION

Microbunching instability is a detrimental phenomenon in high-brightness electron beams that can lead to significant performance degradation in free-electron lasers (FELs) [1]. MBI arises from the interaction between the electron beam's collective fields and its energy spread, causing the beam to form microbunches, which are localized regions of high electron density. These microbunches can scatter radiation from the FEL, leading to reduced coherence and spectral purity.

One effective method to suppress MBI is to induce a controlled amount of energy spread in the electron beam using a laser heater. The energy spread introduced by the laser heater disrupts the microbunching process and prevents the formation of dense microbunches. Traditionally, Gaussian transverse laser modes have been employed for laser heating. However, recent studies have shown that Laguerre-Gaussian (LG) modes offer superior MBI suppression capabilities.

METHODS AND RESULTS

The LG01 transverse laser was generated using a spiral phase plate (SPP) [1]. The SPP was programmed to create a phase mask that transformed the Gaussian beam. The phase mask introduced a 2π phase shift leading to a spiral. This translates to a donut shape in the intensity distribution. The donut shapes allow for the light to be controlled better which leads to less microbunching. When comparing the energy spread of the two laser heaters, the LG01 laser had even Gaussian distributions at higher laser energies. In contrast, the Gaussian beam produced a double-horn energy spread which in part is due to the spot size of the laser being bigger than the electron beam [Figure 1]. In other words, when doing an R^2 fitting, it was found that the Gaussian heat laser produced some jitter at higher energy spreads and which was not found with the LG01 laser, making the LG01 a better MBI suppressor.

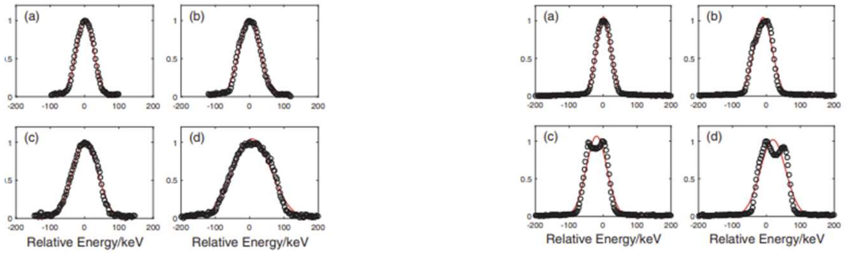

Figure 1: The left cluster are the energy spreads for the LG01 laser heater ranging from (a) 25.1 keV to (d) 55.7 keV. On the right is the Gaussian fitting for (a) 20.5 keV to (d) 37.2 keV. (Ref [1])

FURTHER INTERPRETATIONS

Another interesting approach to reducing microbunching instability is through the Bessel Gaussian beam. The Bessel beam is characterized by a central core surrounded by concentric rings of light. It exhibits unique properties such as self-healing and propagating without spreading.

The Bessel beam can be described as:

$$E(r,\varphi,z) = A\exp\left(i(\frac{2\pi}{\lambda}cos\theta)z\right)J_n\left(\frac{2\pi}{\lambda}sin\theta)r\right)\exp\left(\pm in\varphi\right) \tag{1}$$

which is considered to be a set of Gaussian plane waves propagating on an axion cone as seen in Figure 2 [2]. The angle of the cone is defined as:

$$\theta = (n-1)\gamma \tag{2}$$

where γ is the opening angle on the axion and n is the refractive index [2]. When exploring the 1st order Bessel beam (J_1), it produces a “donut” shaped laser in its center [Figure 3].

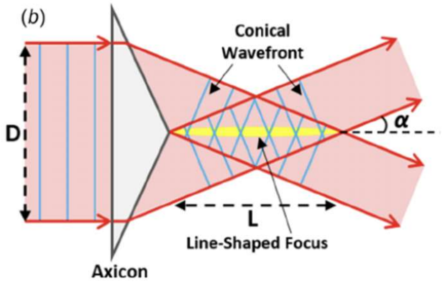

Figure 2: An axion creating a Bessel-beam (Ref[3])

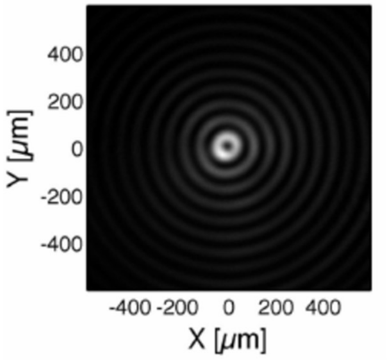

Figure 3: (a) First-order beam. (Ref[4])

Similar to the LG01 laser, this donut shape allows for less power to be used in correcting the MBI. It would be the electric field of the donut affecting the electrons, not the laser itself as is the case of a Gaussian laser heater, making it a good alternative to the LG10 laser. Furthermore, when using an axicon or conical lens to create the Bessel wave, it utilizes most of the incident power from a Gaussian laser beam, making it energy efficient [2].

Its propagation properties can be explored from equation 2. We can find the radius of the spot size to be:

$$r_b = \frac{2.40}{\frac{2\pi}{\lambda} sin\theta} \tag{3}$$

which shows that it is not being changed as it propagates leading to its nondiffracting properties [5]. This is ideal as having less diffraction reduces the likelihood of microbunching occurring. The spot size is useful in order to match it with the electron beam. The conical angle and spot size are inversely proportional meaning a larger conical angle would lead to a smaller spot size.

CONCLUSIONS

The results of the experiment showed that the LG01 laser heater is more effective at suppressing MBI than a Gaussian laser heater. The donut shape was shown to produce a smaller energy spread. A Bessel-Gaussian laser is another laser heater that produces donut shaped modes that have nondiffracting properties making it another good option to reduce MBI.

While there are other aspects that can play a role in energy efficiency, more research would need to be conducted to fully understand the potential benefits and drawbacks of Bessel Gaussian beams for suppressing microbunching. However, a current useful application for the Bassel laser is in Simulated label-free autofluorescence-multiharmonic (SLAM) microscopy which is imaging living tissues at better resolutions [6].

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