UCLA
Recent Work

Title
Sceintific Review Paper

Permalink
https://escholarship.org/uc/item/8633m9zz

Author
Mergia, Yohannes

Publication Date
2022-12-09

eScholarship.org Powered by the California Digital Library
University of California

Review of Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression in Free-Electron Lasers

Yohannes Mergia

Samueli Electrical and Computer Engineering Department, Optica, 420 Westwood Plaza, Los Angeles USA

ymergia982@g.ucla.edu

Abstract: Suppression of Microbunching instability using a LG01 transverse laser mode and compare the improved results with respect to traditional Gaussian transverse laser mode

INTRODUCTION

Free Electron Lasers (FELs) consist of an electron beam that is propagating in a magnetic field. These beams are used heavily in research in biophysical science, medical application, solid state physics, chemical technology etc. Instead of using stimulated emission from atomic or molecular excitation, relativistic electrons are used as a gain medium [3]. The quality of these lasers can be degraded due to microbunching instability (MBI). This not only amplifies the electron beam energy but also the beam brightness [4]. Some of the causes of these are longitudinal instability due to beam coupling impedance and coherent radiation which is the low frequency part of familiar synchrotron radiation in bending magnets [2]. The effects of MBI can be suppressed using a laser heater (LH) which modulates and increases the energy of spread of the electron beam by about one order of magnitude [4].

Current LHs use a simple transverse Gayssian shaped laser. This method is not an effective method of reducing MBI since double horns are created due to the fact that the spot size is bigger than the electron beam. This is created to counter the transverse jitter that is eventually created from the given process [4]. An alternative method is to use unconventional laser beam shapes such as the transverse Laguerre-Gaussian 01 (LG01) which provides an exponential suppression in micro bunching gain. Using theoretical and experimental means, this method of Gaussian-shaped energy distributions is induced and better MBI gain suppression achieved. This leads to high spectral brightness [4].

METHODS

A spiral phase plate (SPP) is used to convert the gaussian distribution input profile into a donut shaped energy ring with zero energy at the center by mapping the once Gaussian transverse distribution of the electron beam to its longitudinal plane [4] . It controls the phase of the transmitted beam using its unique optical properties that arise from spiral or helical phase steps. It increases angular momentum of the vortex beam and the dimensions magnification of the ring intensity pattern [5]. This introduces a challenge where only a small fraction of the laser power can be used but this is remedied by using a high power LG01 laser beam. In this experiment it was found that there was a 95 percent transmission efficiency [4].

RESULTS AND INTERPRETATION

It was observed in the first 135 MeV spectrometer that for either of the transverse shapes that the energy distribution can be tuned by varying the IR laser energy. Since it is possible for the electron beam to be heated to a maximum laser energy of 65 keV, it is possible to adequately study underheating and overheating in FEL which has optimal MBI suppression at 20 - 30 keV [4]. The LG01 mode laser preserves the Guassian-shaped distribution. The Gaussian mode laser heater induced energy distribution at different induced energy spreads. As this energy spread increases, the distribution shows double horn structure. LG01 mode laser induces more Gaussian-shaped energy distribution but as the average R^2 decreases as high energy due to laser transverse jitter [4].

The second primary diagnostic that allows characterization of MBI at high longitudinal-space frequency from secondary electron beam emission. The higher frequency components correspond to shorter longitudinal density moulations while the lower frequencies represent the electron beam as a whole [4]. This method of MBI suppression is particularly very effective in increasing seeding and harmonic lasing spectral monochromaticity and brightness [4]. Now this can have an immense impact in x-ray spectroscopic techniques since MBI is the prime cause of pedestal structure and MBI can be significantly reduced using LS techniques which use LG01 mode lasers. “This start-to-end simulations have shown that the LG01 mode LH could lead to 20% better monochromaticity within 1 eV in the SXRSS spectrum” [4].

The double horn energy distribution can occur at high energies where the LH and electrical beam spatial overlap due to acoustic and thermal noise. The accuracy of the theory regarding the transverse jitter effect can be verified with experiment using an online camera image of the LH interaction point. As expected, it was found that the jittering distance is correlated with the distribution structure.

CONCLUSIONS

It was established that MBI suppressions can be achieved by utilizing LG01 transverse mode LH which induces Gaussian energy distribution as opposed to conventional methods using Gaussian mode LH. Electron beam energy spread by LG01 mode laser beams which have been converted from Gaussian beams. The impact of LH on SXRSS performance and its monochromaticity or spectral brightness was also studied. This can have a wider range of impact on the next generation of engineered laser heater design. This adacement can be used to make powerful optical tweezers to apply force to submicron particles or to measure mechanical properties of macromolecules. This can have a huge impact in the field of medicine where it can be used to analyze different disease causing organisms and design much more effective drugs to cure them. It can also be used in material science to manufacture new kinds of material that will have a wide range of applications on people's everyday life. Another field where this can be helpful is in the future of augmented brightness linacs and x-ray FELs. Better x-rays provide the capacity for doctors to diagnose disease much more efficiently and accurately which will allow them to save countless lives.

REFERENCES

1. Lasheen, Alexandre, and Geneva Switzerland. *Longitudinal Space Charge in the SPS*. 2016.
2. Novokhatski, Alexander. *Coherent Synchrotron Radiation: Theory and Simulations*. 2012.
3. O'Shea, Patrick G., and Henry P. Freund. "Free-Electron Lasers: Status and Applications." *Science*, vol. 292, no. 5523, 8 June 2001, pp. 1853–1858, 10.1126/science.1055718.
4. Tang, Jingyi, et al. "Laguerre-Gaussian Mode Laser Heater for Microbunching Instability Suppression in Free-Electron Lasers." *Physical Review Letters*, vol. 124, no. 13, 30 Mar. 2020, 10.1103/physrevlett.124.134801.
5. Watanabe, Takeshi, et al. "Generation of a Doughnut-Shaped Beam Using a Spiral Phase Plate." *Review of Scientific Instruments*, vol. 75, no. 12, Dec. 2004, pp. 5131–5135, 10.1063/1.1819555.