Title
Laguerre-Gaussian Mode Laser Heater

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Abstract: A scientific review of Tang, Jingyi, et al. "Laguerre-gaussian mode laser heater for microbunching instability suppression in free-electron lasers." Physical review letters 124.13 (2020): 134801. We review the researchers' evidence that a Laguerre-Gaussian mode laser heater should outperform a Gaussian mode laser heater for microbunching instability suppression.

INTRODUCTION

A free-electron laser is a type of laser which is useful due to its ability to provide very short pulses of high-intensity light[1]. To achieve this, a magnetic bunch compressor produces bunches of electrons so that a very high peak current is achieved for a short time[2]. However, the current in these bunches is unstable – small perturbations in the input lead to large perturbations in the output[1,2]. The instability can be suppressed by using a laser heater to increase the energy spread of the electrons[1,2]. The paper establishes that a laser heater using Laguerre-Gaussian-01 mode suppresses the instability better than one using a simple Gaussian mode[1].

METHODS

The researchers measured the energies of each electron in the bunches produced by a magnetic bunching compressor suppressed by a laser heater at different laser heater energies for both a transverse Gaussian laser heater and a Laguerre-Gaussian-01 laser heater constructed by converting a Gaussian mode laser to Laguerre-Gaussian using a spiral phase plate[3]. A spiral phase plate is an optical device resembling a spiral staircase, with each step delaying the beam by a different phase[3]. Destructive interference caused by the phase differences converts the Gaussian mode beam into a Laguerre-Gaussian beam[4]. The transverse size of the electron beam was 50 μm, the transverse size of the Gaussian mode laser heater beam was 100 μm, and the transverse size of the Laguerre-Gaussian-01 laser heater beam was 325 μm[1].

The researchers measured the energy of each electron fired in multiple bunches across different laser heater energies, fit a Gaussian distribution to the energies in each bunch of electrons, and computed the average of the R^2 values over 10 bunches for each laser heater energy measured for each mode[1]. The Gaussian shape of the energy distribution is a good indicator for effective microbunching instability suppression because it minimizes the integral $\int_0^\infty G^2(k_0)dk_0$ where G is the microbunching gain and k_0 is the spatial frequency, and high microbunching gain is what causes the microbunching instability[5]. The researchers also used an MIR spectrometer to measure the coherent transient radiation from a film in the path of the electron beam[1]. This can be used to indicate the effectiveness of the microbunching instability because the radiation profile as a function of spatial frequency characterizes the bunching[1]. The researchers confirmed the reliability of these methods by testing the laser heaters in an application: microbunching instability suppression should improve the brightness and monochromaticity of a free-electron laser; therefore, they simulated the interaction to estimate the effect[1]. We also know that the effect of microbunching instability should dominate other effects in the spectral lineshape of the laser[1].

RESULTS AND INTERPRETATION

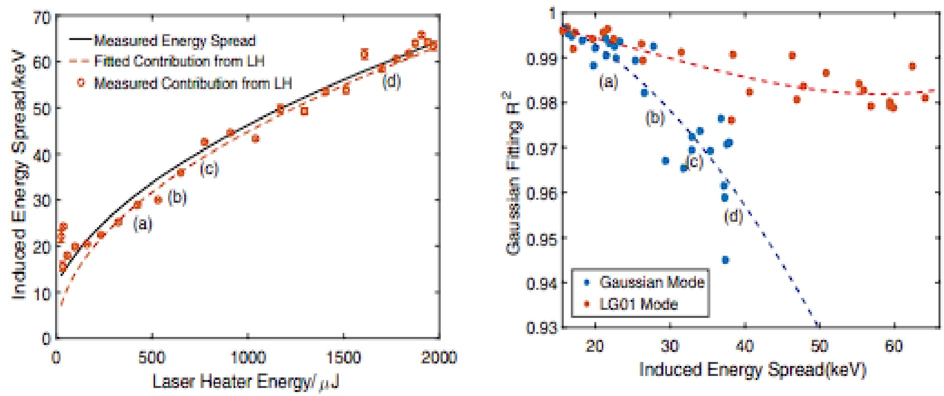

Fig. 1. Relationship between laser heater energy, electron energy spread, and Gaussian fitting R^2 of electron energy distribution (Ref. [1], Fig. 2,3) .

The Laguerre-Gaussian mode laser heater produces electron energy distributions that fit a Gaussian shape well even at high energy spread, where the Gaussian mode laser heater produces poorer results[1]. 20-30 keV of electron energy spread are required to suppress microbunching instability[1]. We can expect that since the Laguerre-Gaussian heater produces a better energy distribution at this energy spread, it will result in lower microbunching gain and therefore better suppress microbunching instability[1]. The integral of the spectral radiation profile over spatial frequencies of interest is lower for the Laguerre-Gaussian heater than for the Gaussian heater in the 15-20 keV range of electron energy spread in the bunches, so we can expect that the Laguerre-Gaussian heater performs better in that range[1]. Also, the simulation shows that the Laguerre-Gaussian heater could produce better monochromaticity in the free-electron laser[1].

CONCLUSIONS

The paper establishes experimental evidence that a Laguerre-Gaussian laser heaters outperform simple Gaussian laser heaters for microbunching instability suppression in magnetic bunch compressors, where previously the idea had only been explored theoretically. While the researchers did not measure the microbunching instability suppression directly, the indirect evidence is enough to prefer the Laguerre-Gaussian mode laser heater for next-generation devices.

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