Title

A Review of an Experimental Method for Microbunching Instability Suppression in Free-electron Lasers

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A Review of an Experimental Method for Microbunching Instability Suppression in Free-electron Lasers

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Abstract:

The effectiveness of using a transverse Laguerre-Gaussian 01, compared to a traditional transverse gaussian, mode in laser-heating of a free electron laser is experimentally verified. The new method's implications for other applications are considered.

INTRODUCTION

Used in a wide variety of frontier fields from complex materials to the life-sciences, free-electron lasers (FEL) produce pulses of coherent, extremely bright, and short wavelength radiation. FEL systems, which act as amplifiers for a given input signal, first and foremost require high-current, high-brightness, and relativistic electron beams, typically created with magnetic compression; for example, with linear accelerators.[2]

To accelerate an electron beam to near the speed of light, it will pass through an array of magnets with alternating poles known as an undulator.[5] It is mentioned by the authors that one of the possible applications that the new mode may be used for is in self-seeding FEL emission, where a high energy laser is provided as a "seed" for the startup process of a FEL.[3]

For high brightness particles transport at close to the speed of light in an accelerator hundreds of meters long, collective emergent phenomena can degrade the performance of a FEL system, decreasing its coherency and brightness. The broad mechanism for this degredation is called microbunching, and it is caused by coherent synchornous radiation (CSR) and longitudinal space charge (LSC) effects, among other things.[2] CSR is where relativistic charged particles subject to a perpendicular acceleration, like the Lorentz force, release photons to conserve energy typically along a curved path.[8] Microbunching will induce instabilities that alter the energy and density characterstics of a given beam, increasing the energy distribution spread that will ultimately reduce the FEL gain.[4] To minimize microbunching instability (MBI), one can use a laser heater to induce an increased energy spread within the electron beam.[7] This favorable energy spread will suppress MBI through Landau damping; an equilibrium occuring because of the energy exchange between the faster-moving EM wave and the statistically slower-moving oscillating particles, assuming a Maxwellian distribution, in the surrounding gain medium.[6]

When using laser heating in a practical setting, transvere jitter, or pulse-to-pulse trajectory instability, must be considered as it will have a significant impact on the energy distribution induced within the beam.[1] As we will see the transverse jitter must be considered for novel modes used in laser heating.[7]

Transverse Laguerre-Gaussian (LG) modes are a subset of gaussian modes that describe a gaussian mode profile with cylindrical coordinates: where Hermite-gaussian modes have rectilinear symmetry in the transverse plane, LG modes have circular or radial symmetry.

METHODS

The initial transverse gaussian profile of the LCLS was converted to LG01 using a spiral phase plate. In order to describe the energy distribution induced by the LG_01 laser heating, a 135MeV spectrometer with a resolution of 2.9 keV per pixel was placed after the LH. As shown in Fig. 1 below, the the electron beam was heated up to at most 65 MeV with maximum laser energy. As shown in Fig. 2, with an LG_01 mode even as the laser power increased from 25.1 keV to 55.7 keV the energy distribution of the bean still maintained a gaussian shape, as opposed to the distribution transition one would see, parabolic to double-horned, with a traditional gaussian mode for the laser. The authors measured the gaussian fit with the R^2 fitting coefficient. As energy increased the fitting coefficient only decreased by approximately 1%. Further along the linac when the beam reached a final energy of 4GeV, the second measurement was taken using a midinfrared (MIR) spectrometer to characterize the bunching profile of the electron beam. As shown in Fig. 3, with a lower coherent signal contribution signalling a reduction in MBI, in the ranges of 15-20keV the LG01 is more effective at reducing MBI than the traditional gaussian.

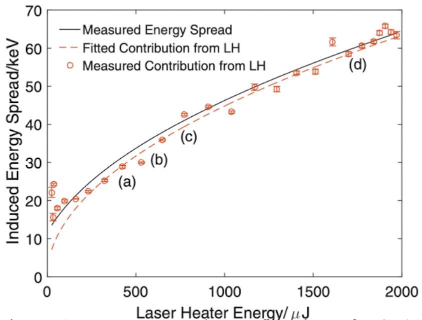

Figure 1. Energy spread as a function of LG_01 laser energy.

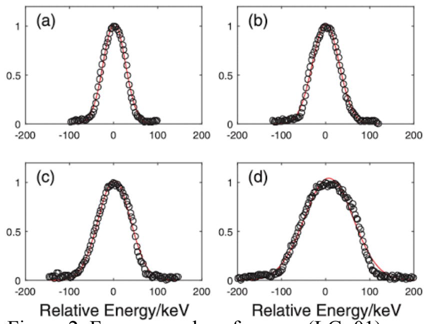

Figure 2. Four examples of energy (LG_01) spread and their distributions with (a) 25.1, (b) 30.3, (c) 36.8, and (d) 55.7 keV rms corresponding Gaussian fits.
energy spread and their corresponding Gaussian fits

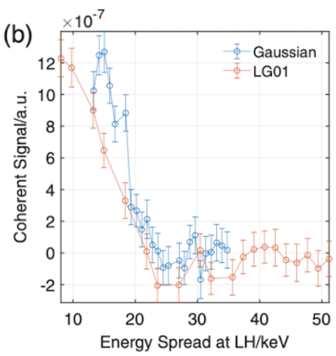

Figure 3. integrated MIR spectral intensity for k ∈ ð3000; 5000Þ cm−1 as a function of induced energy spread by both the LG01 and Gaussian mode LHs.

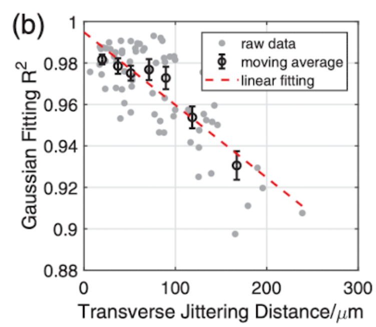

Figure 4. Correlation between the Gaussian fitting R2 of the energy distribution and radial distance laser jittering away from the optimal position

To gain some insight into the MBI reduction effect on soft x-ray self-seeding, where a laser is used to “seed” an FEL system startup process and since there are no mirror-materials that can reflect x-rays you have to rely on one pass of the undulator, the authors simulated the SXRSS process. They showed that using LG01 might lead to a 20% increase in monochromaticity, but no direct comparison was possible.

To verify the impact of transverse jittering on LG01, a camera was placed in the LH to quantify the jittering. As shown in Fig. 4, as the jittering distance increased for the LG01 mode, the gaussian fit decreased.

RESULTS AND INTERPRETATION

The energy spread induced by the LG01 LH had a high gaussian R^2 coefficient of fit. MBI is suppressed more efficiently using a LG01.

The paper touches on the electro-magnetic collective effects that both stabilize, for example the landau effect, and destabilize, such as longitudinal-space charge effects; I would be interested in furthur exploring those effects. In addition, the experiments used two spectrometers to measure various properties of the beam, and I am interested in learning more about how such devices function, and how they operate at such extremes.

CONCLUSIONS

The LG01 mode used in laser heating was shown to be more effective at suppressing MBI instability and, therefore, in improving the performance of the FEL system compared to the traditional gaussian mode LH. The LG01 LH consistently induced a gaussian energy spread distribution over a range of laser powers. Superior performance of the LG01 in SXRSS explored without definitive answers. The results will hopefully be used to furthur progress on X-ray FELs and more efficient FEL systems.

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