SIMULATION AND ANALYSIS OF LASER/ELECTRON BEAM INTERACTION FOR USE AS A FREE ELECTRON LASER

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Abstract

Through the use of simulation tools and theoretical analysis techniques, the Free Electron Laser process is investigated for a wiggler that is generated by an ultrafast laser system. The development and availability of such systems allows for novel FEL designs due to the high peak power of such lasers. Even though such high powers are possible, difficulties arise due to inhomogeneity in the laser pulse. This project looks at simulation results for a system with a realistic laser pulse profile and looks in to the pulse-shape effects on various system parameters. Models are presented for the expected behavior with important parameters noted, as well as highlighting possible difficulties that might occur experimentally. While head-on interaction has been proven experimentally for the short wavelength regime [1], we believe that using a co-propagating laser can provide benefits that have currently been untested. This experimental setup is outlined in Lawler, J et al [2], and we are currently simulating how the use of an ultrashort laser pulse as an electromagnetic wiggler will affect characteristics of the output radiation.

INTRODUCTION

Free electron lasers (FELs) are a highly tunable, flexible light source, with significant opportunities to act as high power, low wavelength sources for industry and research. An FEL relies upon a highly periodic, alternating field to take advantage of electron motion to generate light. Current undulator designs require the use of strong magnets or electro magnets to generate a strong enough field, and often need to be quite long to obtain the desired level of coherence in the output light.

Several new undulator designs have been proposed and tested, including a microwave undulator [3], and several designs have been proposed for optical undulators of various design [4], [5], and a co-propagating optical design [2].

Recent advances in the peak energies possible with ultrafast laser sources and in beam shaping and control allow for the use of optical pulses as an undulator. This allows for a significant decrease in the required length of an undulator and allows for the use of lower electron beam energies while still generating low-wavelength light. The miniaturization of the system leads to several advantages, not the least of which is a significant decrease in cost. In addition, the use of a laser pulse as the undulator allows for the use of COTS components for the transport and shaping optics.

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This paper presents results of a simulation of the proposal from Lawler, et al, in reference [2], modified by the use of an ultrafast laser. This design uses a co-propagating, sheared laser pulse to generate an undulator-like field.

Proposed Experimental Setup

The experimental design is based on transporting an ultrashort pulse through a series of optical components to shear the wave fronts in to a uniform, undulator-like design. Several methods have been considered for how to shear a laser pulse, with various benefits for each depending on the qualities of the incoming laser pulse.

We propose a system using an ultrashort pulse that is sheared using a blazed grating with necessary correction optics and diagnostics. A schematic of the interaction can be seen in figure (1). Several proposals have been made for perpendicular illumination of the beamline, and integrating some of those ideas with ours will be beneficial [6].

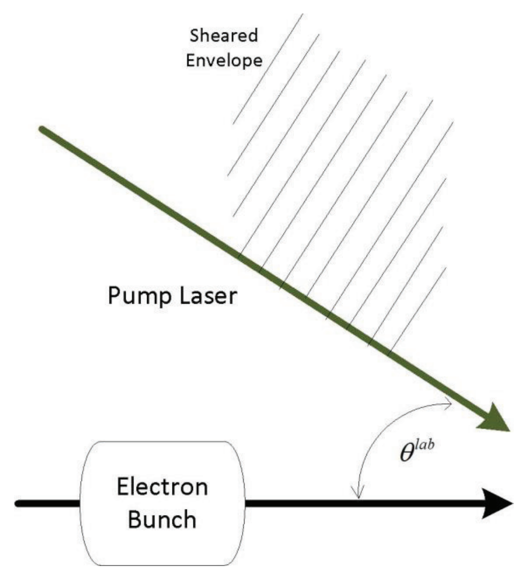

Figure 1: Beam interaction schematic.

Simulation Setup

Two simulation codes were used for simulating the undulator section of the proposed design. ONEDFEL is a 1D, non-time-averaging code, and MEDUSA is a full 3D simulation code [6]. In order to approximate the envelope of an ultrafast pulse, the already built-in feature of undulator tapering was used. This function used a sin2 envelope instead of a Gaussian, but is valid for simulating the effect of such a variable field undulator.

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In addition to the ultrafast pulse approximation, the resonant period of the undulator was calculated using the equation below,

$$\lambda_{x-ray} = \frac{\lambda_{pump}(1-\beta)}{1-\beta\cos\left(\theta^{lab}\right)}. \quad (1)$$

For the purpose of the simulation, the parameters were chosen as in Table 1. These parameters are based-on an idealized, relatively low-energy electron accelerator operating around the resonant frequency calculated above. In our case, supposing an 800-nm pump laser beam, we see an effective undulator period of 2.54 cm. For the simulations in this paper, a 2.54 cm is supposed.

Table 1: Simulation Parameters

Name	Value
Beam Energy	100 MeV
Energy Delta	0.0015 MeV
Beam Profile	Gaussian
Emittance	10 Microns
Undulator Profile	Simulated Gaussian ($\sin^2$)

RESULTS

Variable Output Frequency

It is beneficial to also look at the resonance condition of the undulator at various optical frequencies. The seeded and SASE modes both show a large range of output light, but with similar spectrums. This can be seen in figures (2) and (3) below for the SASE and seeded cases.

In both seeded and SASE cases, peak power can be seen at around 1 um output. The broad features in both figures is due to the variable-K undulator profile.

Gain Curves

The amount of gain is highly dependent on the peak current in the beam. This can be seen in the gain curves below where a small peak current leads to only small gain, but the effect is readily apparent for higher currents. An interesting feature of these curves is in the growth region where there are distinct peaks and valleys in the gain curve that are a geometrical feature of the system, figure (4).

This structure looks to be directly related to the geometric parameters of the system, and its cause is still being investigated.

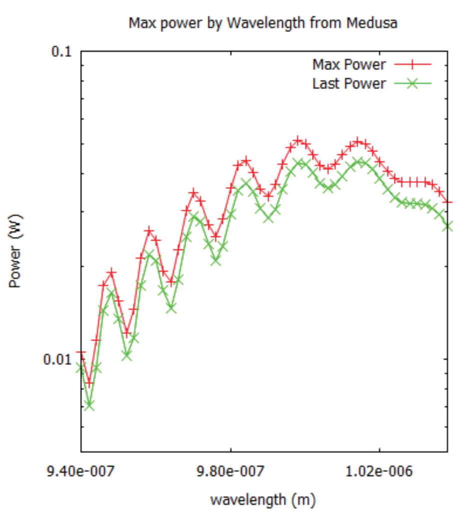

Figure 2: SASE Output Spectrum.

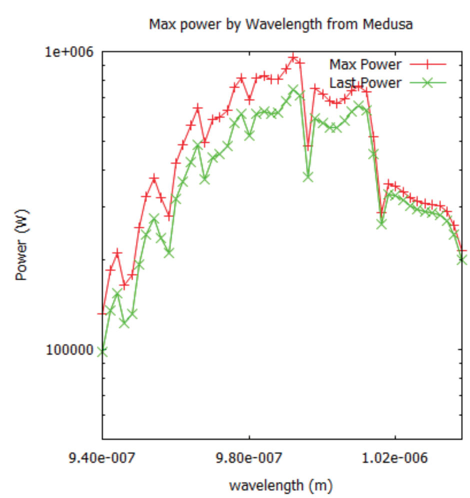

Figure 3: Seeded Output Spectrum.

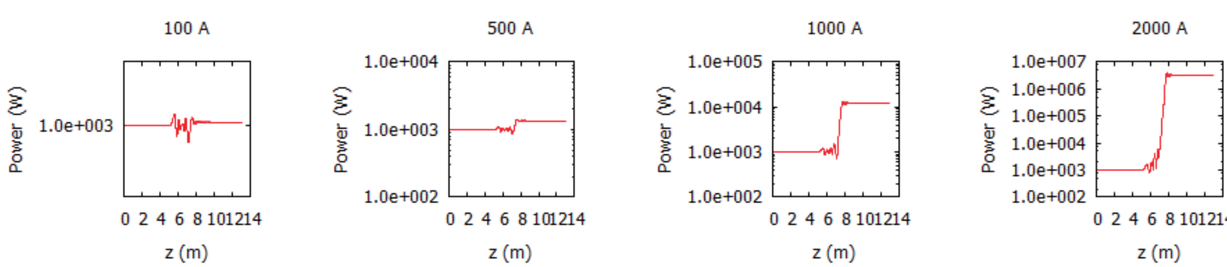

Figure 4: Gain by beam current.

CONCLUSION

From the simulations run above, we can see that using an ultrafast pulse has the probability of working successfully as an undulator for an FEL. Such a design could provide several advantages over current designs, including the use of a smaller accelerator and lower beam energies.

Further research is currently being undertaken to quantify the effects of the transport optical system for the ultrashort pulse. Such effects will have a significant effect on the undulator characteristics, leading to additional harmonics and modal aberrations.

The co-propagating, sheared laser pulse undulator looks to be a successful candidate for a new sort of undulator design. Modal output (not shown in this paper) show no significant aberrations, and the optical nature of the design should lead to increased compactness and flexibility in design.

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