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START-TO-END SIMULATION OF THE NSRRC SEEDED VUV FEL

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Abstract

A free electron laser (FEL) driven by a high brightness electron linac system has been proposed to generate ultra-short intense coherent radiation in the vacuum ultraviolet region. It is a third harmonic high-gain high harmonic generation (HGHG) FEL for generation of VUV radiation with wavelength at 66.7 nm from a 20 mm period length helical undulator. A 200 nm seed laser is used for beam energy modulation in a 10-periods helical undulator of 24 mm period length. A small chicane is placed between the two undulators to optimize power growth in the radiator. In this study, we perform start-to-end simulation to foresee the operational performance of the test facility and preliminary results are presented.

INTRODUCTION

The VUV FEL is a third harmonic HGHG FEL seeded by a 200 nm laser. The beam energy modulator is a 10-periods helical undulator with 24 mm period length. The radiator is also a helical undulator but of 20 mm period length which allows generation of high power coherent radiation at 66.7 nm wavelength [1]. Schematics of the NSRRC seeded VUV FEL is shown in Fig.1. The FEL is driven by a linac system that delivers a 100 pC, ~250 MeV high brightness electron beam. It is worth noting that a dogleg bunch compressor with linearization optics is used [2]. In this study, we perform simulation of beam dynamics in the proposed system starting from photoinjector cathode to FEL output. Space charge tracking in the photoinjector is done by GPT code [3], tracking of particles in the bunch compressor and linac systems is done by ELEGANT [4] and 3D time-dependent simulation of high gain FEL using GENESIS [5]. Data transfer between these two codes is done with SDDS [4].

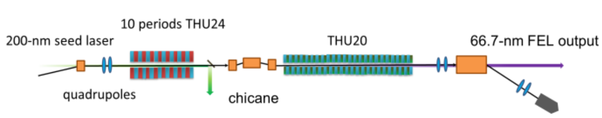

Figure 1: Schematics of the NSRRC third harmonic HGHG FEL.

Simulated drive beam properties by GPT and ELEGANT such as electron distribution in longitudinal phase space and beam current profile are summarized in the next section. The third section shows preliminary GENESIS simulation results of FEL interactions in modulator and radiator. The last section is the conclusions and summarized the direction for future study.

DRIVE BEAM

The bunch compressor designed for the driver is a double dog-leg configuration that provides a first order longitudinal dispersion function (i.e. R_{56}) and linearization optics for correction of nonlinearity introduced into the beam due to rf curvature. Bunch length or the peak current under various operation conditions can be adjusted by tuning R_{56}. It can be realized by changing the longitudinal positions of the outside dipoles of the dogleg compressor and by adjusting the quadrupoles and sextupoles. After bunch compression, the beam is accelerated to designed energy by two rf linac sections. In this simulation study, beam energy is at 263 MeV.

Electron Distribution in Longitudinal Phase Space

There is a residual energy chirp left after bunch compression. The beam is actually slightly over-compressed and the chirp is of ~42 keV/□m. This is tentatively corrected by a 1 m corrugated pipe dechirper structure [2]. Electron distribution of the dechirpered beam in longitudinal phase space at linac system exit is showed in Figure 2. Sliced energy spread in this case can be as low as 0.05%. In order to save tunnel space, dechirper using rectangular dielectric-lined waveguide is recently under study.

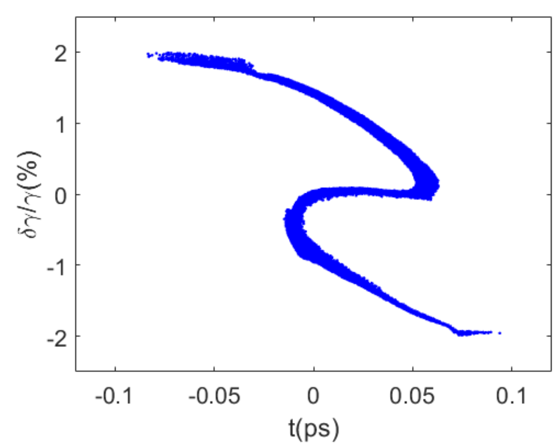

Figure 2: Electron distribution of the compressed beam in longitudinal phase space at linac system exit. Residual beam energy chirp is compensated by a 1 m corrugated pipe dechirper.

Beam Current Profile

After the dogleg bunch compressor, the 100 pC beam is compressed into 51 fs in duration so that the beam current profile is roughly uniform in the middle part. Fig. 3 shows

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the current profile at linac system exit. Nominal peak current is about 800 A at the bunch centre.

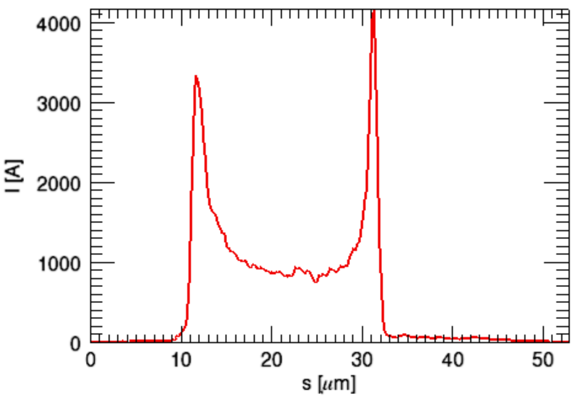

Figure 3: Beam current profile of the compressed beam at the exit of the drive linac.

HGHG FEL SIMULATION

3D time-dependent simulation of HGHG FEL is divided into two parts. First, we calculate beam energy modulation by the 200 nm seed laser in THU24 undulator. The second part is the beam-wave interaction in the radiator but with a small chicane placed upstream. The drive beam data from ELEGANT is converted from SDDS format to ASCII data format by the SDDS code for FEL simulation with GENESIS. A pair of quadrupoles has been used to minimize betatron oscillations in the radiator (see Fig. 1).

Beam Energy Modulation

The seed laser is coupled into the first helical undulator (i.e. THU24) for beam energy modulation. While betatron oscillation in THU20 is minimized by optimizing beam size at its entrance, beam size at THU24 entrance is at ~300 □m. Seed laser spot size is set at about three times of the beam size at modulator entrance (i.e. Rayleigh length equals to 20 m). In this context, an energy modulator of 0.14% can be achieved for laser power at 300 MW. Figure 4 depicts the distribution of the energy modulated beam in longitudinal phase space after the THU24 helical undulator.

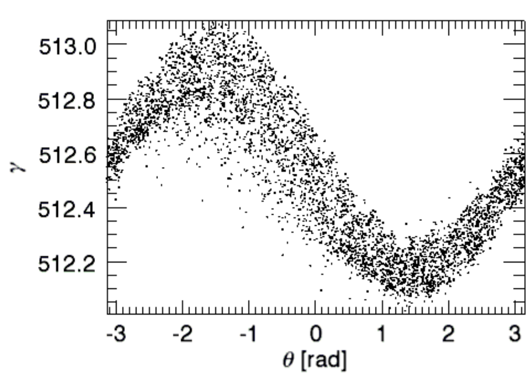

Figure 4: Distribution of the energy modulated beam in longitudinal phase space after the THU24.

Dispersive Section

The purpose of the dispersive section is to provide necessary microbunching at 200 nm spacing so that coherent harmonic undulator radiation can be generated in roughly the first two gain length. Such coherent is acted as the seed for high gain FEL interaction in the radiator [6]. The dispersive section is a simple four-dipole chicane. Strength of the dipole magnets are optimized for fastest power growth in the radiator. It is found that at 0.1 T dipole strength, the saturation length of the 66.7 nm radiation is the shortest.

Power Growth in Radiator

The VUV radiation is saturated at about 3.5 m with an output power of 240 MW. This result is in good agreement with the prediction of saturated output power by Xie's fitting formula [7]. Radiation power growth along beam axis is shown in Fig. 5 . In the first few gain length, the prebunched electron beam by laser-beam interaction in the modulator THU24 radiates coherently at third harmonics of the seed laser. Coherent undulator radiation power at 1.5 m undulator length is about 15 MW. As microbunching (at 66.7 nm spacing) in THU20 becomes significant, the VUV radiation growths exponentially and saturates at ~3.5 m.

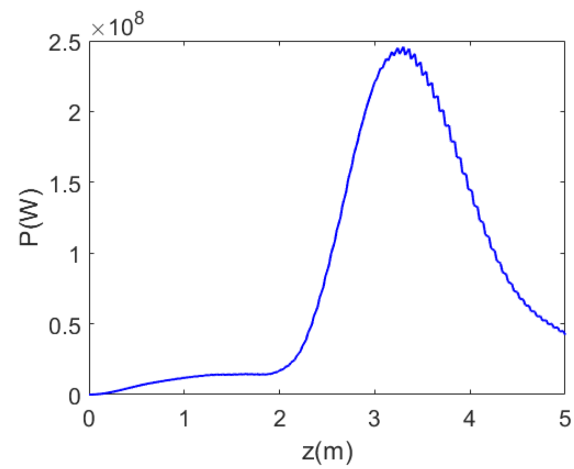

Figure 5: Evolution of VUV radiation in THU20 helical undulator.

Table 1: HGHG FEL Parameters at 66.7 nm Operation

Modulator period [mm]	**24**
Modulator parameter *K*	1.84
Modulator length [m]	0.24
Seed laser Rayleigh range [m]	20
Seed power [MW]	300
Radiator period [mm]	20
Radiator parameter *K*	0.867
Radiator output power [MW]	240
Electron beam energy [MeV]	263
RMS beam size [□m]	260
Normalized emittance [mm-mrad]	3
Peak current [A]	800
Beam modulation [%]	0.14
Magnet strength of 4-dipole chicane [T]	0.1

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CONCLUSION

In this start-to-end simulation study, we obtained a distribution of ~800 A, 51 fs compressed electron beam from GPT/ELEGANT simulation and transfer the output data to GENESIS at input and simulated the beam-wave interactions in modulator and radiator of a third harmonic HGHG FEL. Saturated output power of 240 MW can be obtained at 66.7 nm wavelength. A set of preliminary operational parameters is listed in Table 1. The properties of the drive beam from the high brightness linac system as well as the FEL interaction are by no means optimized. Further optimization of operational parameters is absolutely necessary. Further, the effects of undulator and laser field errors have to be investigated for engineering design. It has to be pointed out that the effect of coherent synchrotron radiation (CSR) occurred in the small chicane is neglected. We believe that it is insignificant for such a low energy beam and the chicane field strength is relatively weak.

More sophisticated seeding schemes such as EEHG [8] and energy-cooled HGHG [9] are obviously topics for future studies.

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