SIMULATION STUDY OF THE NSRRC HIGH BRIGHTNESS LINAC SYSTEM AND FREE ELECTRON LASER

W.K. Lau, C.H. Chen, H.P. Hsueh, N.Y. Huang, NSRRC, Hsinchu, Taiwan
J. Wu, SLAC National Accelerator Laboratory, Menlo Park, USA

Abstract

A 263 MeV linac system has been designed to provide a high brightness electron beam for the NSRRC VUV FEL test facility. This system is equipped with a dogleg with linearization optics to compensate the effects of nonlinear energy chirps introduced into the system by the chirper linac voltage during bunch compression. In this study, we performed start-to-end simulation to illustrate the capability of this linac system to generate a beam that can be used to drive a SASE FEL to saturation within reasonable undulator length. It has been demonstrated that, for a 200 pC beam, such FEL has a saturated output power of ~200 MW at 6-m undulator length. Further optimization of bunch current profile and momentum spectrum is required.

INTRODUCTION

Baseline design of the NSRRC VUV free electron laser (FEL) test facility is a high-gain harmonic-generation (HGHG) FEL driven by a 263 MeV driver linac and a tunable seed laser [1]. Besides the existing photoinjector system [2] and rf linac sections used to boost beam energy, the system is equipped with a 130 MeV dogleg bunch compressor which has linearization optics to compensate of the effects of nonlinear energy chirp inherited from the chirper linac voltage [3]. In the design, a planar undulator of 100-mm period length (U100) is employed for beam energy modulation in cooperate with a tunable seed laser as well as a 20-mm period helical undulator (THU20) is used for emission of radiation at the fourth harmonic of the seed laser frequency [4]. A small chicane is added to control bunching factor before the beam enters the radiator. Radiation wavelength is tunable from 66.5 nm to 200 nm by tuning simultaneously the seed laser wavelength and the undulator parameter of THU20. In comparison with a planar undulator having the same period length and peak magnetic field, helical undulator has the advantage of more efficient beam-wave interaction in the high gain section and therefore shortened the saturartion length.

The driver linac system has been designed and studied extensively with GPT [5] and elegant [6]. It is now under construction at NSRRC and operation condition has been determined for initial FEL experiments. In this study, we perform start-to-end simulation to demonstrate the capability of this linac system to generate a high brightness electron beam that can be used to produce self-amplification of spontaneous emission (SASE) from long THU20 undulator. In order to reduce the residual energy chirp after bunch compression, a corrugated pipe dechirper has been used. Genesis simulation [7] for a SASE FEL driven by such beam from this driver linac will be discussed.

THE DRIVER LINAC

The bunch compressor for the driver linac consists of a 3-m chirper rf linac section and a double dogleg configuration that provides a first order longitudinal dispersion function (i.e. R_{56}) with a sign opposite to that of a conventional four-dipole chicane [8, 9]. A large variation in bunch length or peak current for various operation conditions can be obtained by tuning R_{56}. This can be realized by varying the longitudinal positions of the outside dipoles (i.e. varying L_1) for desired bunch compression ratio (Fig. 1). However, the bunch compression ratio is a sensitive function of chirper linac phase and L_1. This will be shown in the following discussion and it affects our choice of operation parameters.

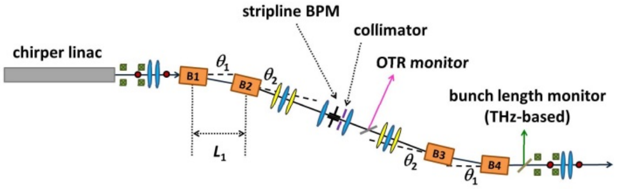

Figure 1: Schematics of the dogleg bunch compressor in the NSRRC drive linac system for the FEL test facility.

Sextupoles are useful to remove the nonlinear energy chirps introduced into the system due to the rf curvature of chirper linac. As shown in Fig. 2, the sextupoles help to remove energy chirps up to second order. The residual energy chirp (usually linear) left after bunch compression can be corrected by a capacitive dechirper structure when the bunch is slightly over-compressed.

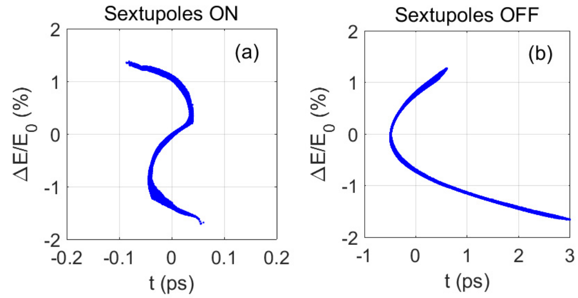

Figure 2: Electron distributions in longitudinal phase space at driver linac exit with all the four sextupoles are (a) optimised for linearization of energy chirps and (b) when all the sextuples are switched off. Electron beam energy at linac exit is 263 MeV and L_1 has been set at 1.313-m in this case.

Determination of Operation Condition

The peak current of a compressed bunch is a sensitive function of chirper linac phase at high compression ratio. Figure 3 shows the variation of bunch peak current at linac exit with respect to chirper linac phase according to elegant simulation. It can be seen from the plot that the compressed bunch current can be as high as a few thousand amperes. However, the system is more sensitive to chirper linac phase at higher bunch current. In practice, it is important to keep phase fluctuation of microwave system low to avoid large pulse-to-pulse variation in bunch current. On the other hand, we consider to operate the system at lower bunch current, say ~1000 A, to mitigate such current variation due to possible phase instability of microwave system.

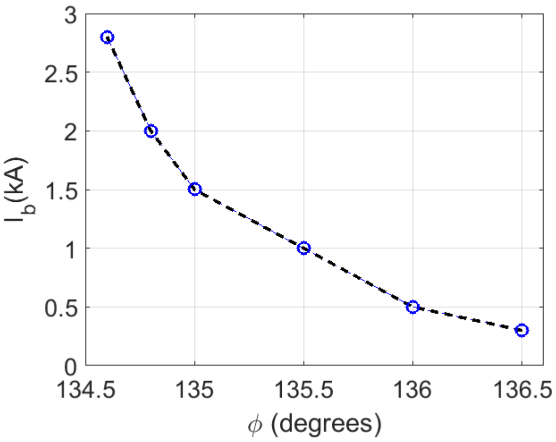

Figure 3: Compressed bunch current versus chirper linac phase at $L_1 = 1.313$ m.

Removal of Residual Linear Beam Energy Chirp

As can be seen from Fig. 2a, there is a residual energy chirp left in the beam after bunch compression. This limits the FEL output pulse duration and energy because only part of the beam lases at designed frequency. It can be removed by adding the longitudinal wake field produced by a dechirper which is usually corrugated metallic pipes or plates [10, 11]. A 1-m long corrugated pipe has been used in this study. Dimensions of this dechirper are listed in Table 1.

Table 1: Dimensions of the Corrugated Pipe Dechirper Used in this Simulation Study

Pipe radius [mm]	1.25
Depth [mm]	0.5
Period [mm]	0.5
Gap [mm]	0.25
Total length [m]	1.0

It is clearly shown in Fig. 4 that the residual energy chirp of the beam can be removed effectively by the dechirper. Current profile and energy spectrum of the beam after the dechirper are plotted in Fig. 5. Beam energy spread has been reduced to less than 1.5 MeV. Since the physical aperture of the 1-m corrugated pipe is relatively small in comparison with the beam size, dechirpers using dielectric slabs is considered to be much more compact in physical size is also under study [12, 13].

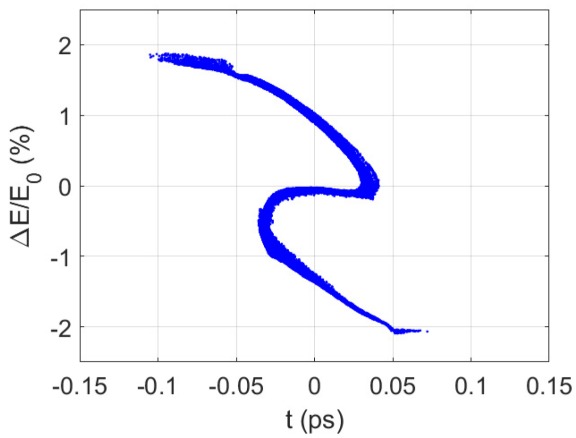

Figure 4: Longitudinal phase space distribution of electrons at driver linac exit. A 1-m corrugated pipe dechirper has been added into the system after the main linac in elegant simulation. Electron beam energy at linac exit is 263 MeV and L_1 has been set at 1.313-m.

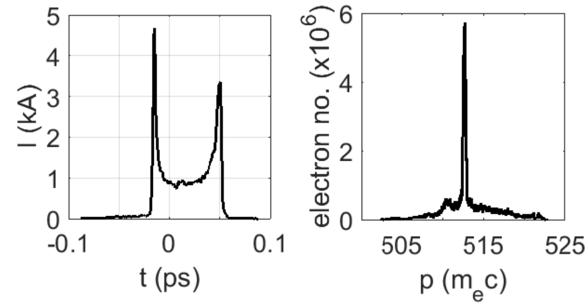

Figure 5: (a) current profile and (b) momentum spectrum of a compressed bunch generated from the driver linac system. A 1-m corrugated pipe dechirper has been added in elegant simulation.

SASE FEL SIMULATION RESULTS

Start-to-end simulation has been carried out to demonstrate the high brightness electron beam generated from this driver linac system can be used to produce SASE radiation at 66.5 nm from the THU20 undulator. The undulator parameter is set at 0.85 according to the resonant condition of the beam-wave interaction in undulator. Nominal beam parameters are summarized in Table 2. Elegant output file of the beam generated from the driver linac at chosen operation condition has been used for SASE FEL simulation with Genesis.

Table 2: Nominal Drive Beam Parameters for Preliminary SASE FEL Simulation with Genesis

Beam energy [MeV]	263
Beam current [kA]	1.0
Bunch length [fs]	~50
Normalized emiitance [mm-mrad]	3.0
Energy spread [MeV]	1.5

Figure 6 shows the growth of radiation power along the THU20 helical undulator. At 200 pC, it saturates at about 6 m with output power of ~200 MW.

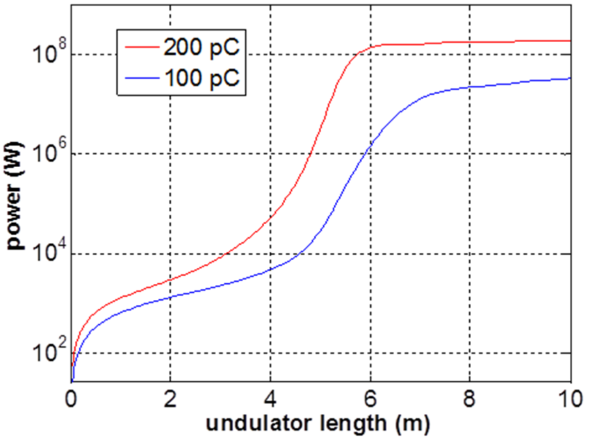

Figure 6: Calculated SASE FEL output power as a function of THU20 helical undulator length.

SUMMARY AND DISCUSSION

A 263 MeV linac system has been designed to provide a high brightness electron beam for the NSRRC VUV FEL test facility. We performed start-to-end simulation to illustrate the capability of this linac system to generate a beam that can be used to drive a SASE FEL to saturation within reasonable undulator length. Preliminary results show that, for a 200 pC beam, such SASE FEL saturates at about 6 m in undulator length and saturated output power of 200 MeV. It is worth nothing that concentration of electrons in the middle of the bunch after bunch compression is important for lasing at high output pulse energy. This is controllable by sextupole strength. Further optimization of bunch current profile and momentum spectrum is required for better FEL performance. Sensitivity of the properties of drive beam to the alignment errors of magnets, stabilities of magnet power supplies etc. are also important issues for further studies. A compact dielectric slabs dechirper with reasonable aperture will also be studied.

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