DESIGN STUDY FOR THE SDUV-FEL FACILITY

Z.T. Zhao, Z. M. Dai, X. F. Zhao, D. K. Liu, Q.G. Zhou, Q. Gu, Y. Xu
Shanghai Institute of Applied Physics, P.O.Box 800-204, Shanghai 201800, P. R.China
D. H. He, Q.K. Jia, S.C. Zhang
NSRL, University of Science and Technology of China, Hefei 230029, China
S.Y. Chen, J. P. Dai
Institute of High Energy Physics, Beijing 100084, China

Abstract

The design study and R&D for the Shanghai deep ultra-violet free electron laser source (SDUV-FEL) are under way. This HGHG based FEL facility consists of a 300MeV linac with photo cathode RF gun and magnetic bunch compressors, a driving and seed laser system and an undulator section including a modulator undulator, a dispersive section and a radiator undulator. In this paper, we present the design study on the FEL physics and the linac beam dynamics, and report the start to end simulation results and the parametric optimizations.

INTRODUCTION

The SDUV-FEL project [1] was proposed by Shanghai Institute of Applied Physics (SINAP), National Synchrotron Radiation Laboratory (NSRL), and Institute of High Energy Physics (IHEP) in 1998. The design and the relevant R&D of the SDUV-FEL facility have been under way since 2000. The goal of this project is to provide a high-brightness coherent deep ultra-violet source (DUV) in the spectral region from 500nm to 88nm, and promote an R&D activity oriented to the development of a coherent X-ray source in China.

Figure1 shows the optimized schematic layout of the SDUV-FEL facility. It consists of a 300MeV S-band linac with photo-cathode RF gun and two magnetic bunch compressors, a driving and seed laser system and an undulator section including a modulator undulator, a dispersive section and a radiator undulator.

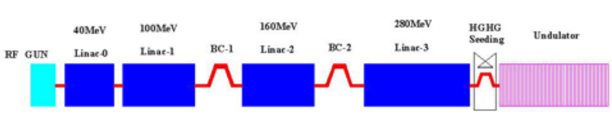

Figure1: Schematic layout of the SDUV-FEL facility

For the time being, a 150MeV electron linac is under construction as the first section of the 300MeV linac. Based on the high-brightness electron beam delivered by the 150MeV linac, the SASE FEL and/or seeded FEL experiments will be carried out in the spectral region from 500nm to 264nm in 2005.

DESIGN OF THE SDUV FEL

To produce stable narrow-band and high-brightness coherent DUV radiation, the well-known HGHG seeding scheme [2] will be implemented in the SDUV-FEL facility. Here, a seed laser at a wavelength of 264nm is injected into the modulator undulator section for energy modulation, and then the modulated electron beam passes through the dispersive section and finally enters the radiator undulator section, which is tuned to be resonant to a wavelength of 88nm, the 3rd harmonic of the seed laser. The main parameters of the SDUV HGHG FEL are summarized in table 1.

Table 1: Main Parameters of the SSRF Storage Ring

FEL parameters	
Wavelength (nm)	88
Gain length L_G (m)	~0.8
Output power (MW)	~100
Electron beam parameters	
Energy (MeV)	276
Bunch charge (nC)	1
Peak Current (A)	400
Nor. emittance (mm·mrad)	4
Local energy spread (%)	0.1
Seed laser parameters	
Wavelength (nm)	264
Input power (MW)	20~50
Rayleigh range (m)	0.8
Modulator undulator	
Length	0.781
Period (cm)	3.55
Peak magnetic field (T)	0.778
Dispersive section	
Dispersion ($d\psi/d\gamma$)	1.0~6.0
Radiator undulator (FODO focusing)	
Period (cm)	2.5
Peak magnetic field (T)	0.62
Section number	6
Section length (m)	1.5
Drift between sections (m)	0.1
Average beta function (m)	~3.5

We first optimized the radiator undulator to obtain minimum power e-folding length L_G at 88nm using the three-dimensional analytical formula of [3] for high-gain FEL. The effects of the undulator segments (undulator section length and drift between undulator sections) and focusing strength on the FEL gain length and saturation power has been studied extensively with GENESIS1.3 [4]. The optimal gain length at 88nm simulated by GENESIS1.3 is about 0.9m, which is approximately equal to the analytical result.

To optimize the parameters of the modulator undulator, dispersive section, radiator undulator and the seed laser, the HGHG process at 88nm has been studied with the three-dimensional analytical theory of [5] for HGHG process and simulated with the modified TDA3D [6]. Fig.2 shows the evolution of the SDUV HGHG FEL at 88nm for different slice energy spreads of electron beam. It indicates that a small slice energy spread is crucial to the HGHG process. The sensitivity of the SDUV HGHG FEL performance on electron beam parameters, such as the current, emittance, energy spread and undulator errors has also been studied.

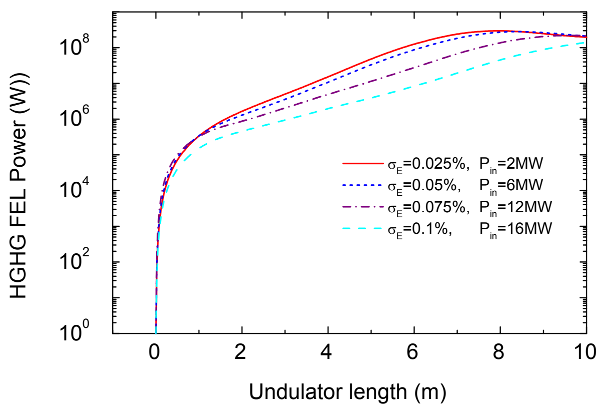

Figure 2: Power vs. radiator undulator length

3 150MEV LINAC DESIGN AND START TO END SIMULATION OF UV SASE FEL

The 150MeV linac, the first section of the 300MeV linac of the SDUV-FEL facility, consists of a BNL type 1.6 cell photocathode RF gun, linac-0, and linac-1, linac-2, a magnetic bunch compressor located between linac-1 and linac-2.

The photocathode-injector, from the cathode to end of linac-0, has been simulated with PARMELA [7]. Then the electron beam was tracked through magnetic bunch compressor and the second to fifth accelerating tubes with help of ELEGENT [8] taking into account a simplified model of coherent synchrotron radiation (CSR) wake. The SASE FEL process at 260nm in the undulator, driving by the high-brightness electron beam from the 150MeV linac, was simulated with GENESIS1.3 based on the output of ELEGENT.

We performed the simulations with the code PARMELA from the cathode to the end of the photo-injector using 2×10^5 macro-particles. The beam current and energy of electron beam, calculated along the bunch, at exit of the photo-injector are presented in Fig.3. The bunch length is about 10ps, the peak current is close 100A, and the global normalized emittance of electron beam at exit of the photocathode-injector is about 2.6mm-mrad.

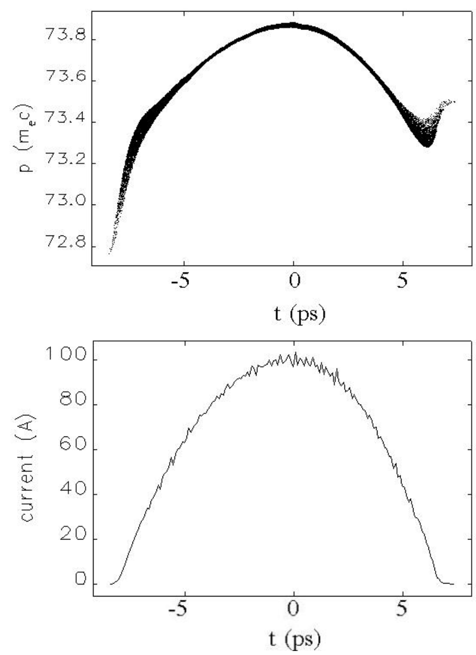

Figure3: Energy and current distribution along bunch at the exit of the injector

At the entrance to linac-1, the output distribution of macro-particles is converted into the input distribution for ELEGENT. It is then tracked through the linac-1 operating at -16 degree, magnetic bunch compressor BC-1, linac-2 operating at 21 degree, and transport line to the radiator undulator. The resulting distribution in the longitudinal phase space for the beam at the entrance to the undulator is presented in Fig.4. The global beam emittance at the end of 150MeV linac is 3.2mm-mrad.

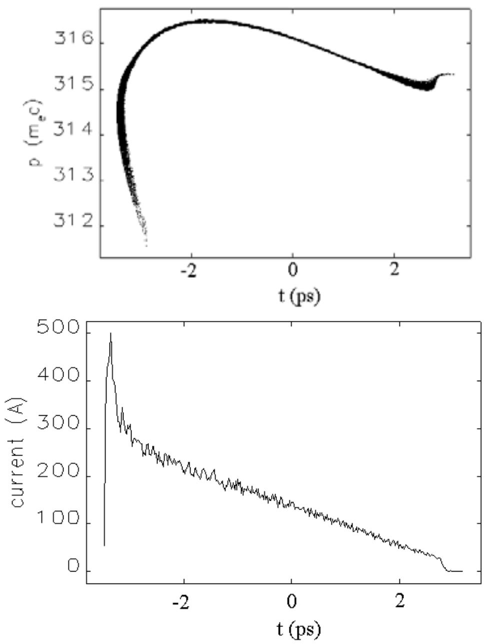

Figure 4: Electron distribution along bunch at the entrance to the undulator

To simulate the SASE FEL process with GENESIS1.3, the electron distribution at the entrance to undulator has been longitudinally divided into 400 slices. The electron beam slice parameters (emittance, energy, energy spread, current, beam size and etc.) have been calculated and saved as a beam description file for GENESIS1.3. And then the SASE FEL process was simulated using 1600 slices based on the beam description file. Fig.5 shows the start-to-end simulation results for SASE FEL process at 260nm, driving by the high-brightness electron beam produced by the 150MeV linac. From Fig.5, one can see that the SASE FEL at 260nm is close to saturation and the peak power at the exit of the undulator is more than 150MW, using the 6 undulator segments optimised for HGHG FEL at 88nm.

CONCLUSION

As a first step towards the high-gain SDUV-FEL facility, the design and R&D are being carried out in three institutes of the Chinese Academy of Sciences: SINAP, NSRL and IHEP. The optimisation of the linac, including the magnetic bunch compressors, and start-to-end simulation of the SDUV HGHG FEL at 88nm are still under way.

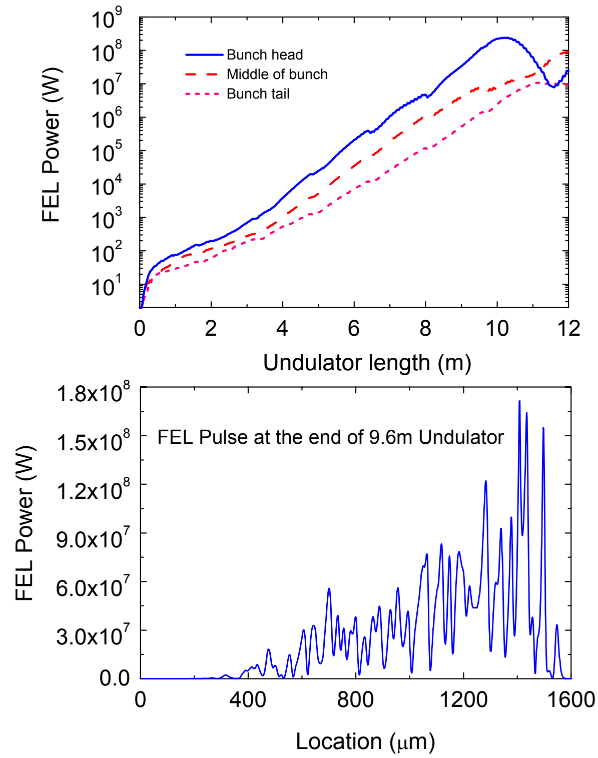

Figure 5: SASE FEL at 260nm

ACKNOWLEDGMENTS

This work is partially supported by the Major State Basic Research Development Programme of China under Grant No. 2002CB713600, the Chinese Academy of Sciences and the National Natural Science Foundation of China, and it has been carried on by the SDUV-FEL project team. We are thankful to all members of the project team and the FEL experts worldwide for their valuable consultation, suggestions, and discussions on the design and R&D of SDUV-FEL.

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