ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK123

INITIAL DESIGN ON THE HIGH QUALITY ELECTRON BEAM FOR THE HEFEI ADVANCED LIGHT SOURCE*

R. Huang, Z. He†, Q. Jia, L. Wang, Y. Lu
NSRL, University of Science and Technology of China, Hefei, Anhui, 230029, China

Abstract

The Hefei Advanced Light Source (HALS) was proposed as a future soft X-ray diffraction-limited storage ring with a Free Electron Laser (FEL) at National Synchrotron Radiation Laboratory (NSRL). We present a design for a high brightness electron source as an injector of a 2.4 GeV linac-based diffraction limited storage ring and a free electron laser. The electron beams with low emittance and high peak current will be generated from a photoinjector and designed to fulfill the requirement of the HALS. To compress the bunch length and enhance the pulse current, velocity bunching scenario by a deceleration injection phase is designed. Owing to a linear compression, the electron beam is expected to be extremely short with a further magnetic compression.

INTRODUCTION

The Hefei Advanced Light Source (HALS) is assembled light sources including a diffraction limited storage ring, and a Free Electron Laser (FEL) covering ultraviolet (UV) and soft X-ray, which is proposed at National Synchrotron Radiation Laboratory (NSRL) in University of Science and Technology of China. The overall layout of HALS is shown in Fig. 1.

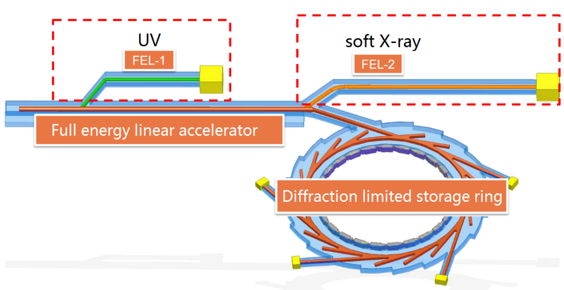

Figure 1: Layout of HALS

According to the assignment of the project, the acceptance criteria of the high quality electron source are listed in Table 1. To achieve a highest brightness, the transverse emittance of the beam must be minimized. A normalized emittance of 2 mm.mrad is required to fulfill the FEL demands. An S-band photocathode rf gun is adopted to generate a short pulse electron beam with a low emittance, a low energy spread and a high peak current. Photocathode rf gun is widely used as an injector of the large-scale scientific facility such as FELs and light sources based on diffraction limited storage rings.

Table 1: Requirements on the Electron Source

Performance	Criterion
rms emittance	< 2 mm.mrad (normalized)
beam energy	4.5 MeV
	stability and energy spread ≤ 1%
electron charge	1 nC
	stability ≤ 1%

PHYSICAL DESIGN OF THE HIGH QUALITY ELECTRON BEAM

The electron source is consist of a photocathode rf gun, laser system, emittance compensation coil (solenoid), power source, beam diagnostic system and other supporting components.

The beam dynamics is simulated by ASTRA code [1]. A Multi-Objective Genetic Algorithm (MOGA) [2] is utilized to optimize the beam line parameters to achieve the lowest emittance.

Sixteen Gaussian (σ_t=1 ps) micro-pulses with 1.5 ps of interval are stacked to realize a plateau time distribution with 23 ps of pulse length (FWHM). To generate the lowest transverse emittance of electron beam, a truncated Gaussian distribution is assumed in spatial profile. Because it has been demonstrated that a quasi-linear space charge field could be realized by a truncated Gaussian distribution [3] with σ_0/r =1. Since the emittance growth from a linear space charge field could be fully compensated by a solenoid coil.

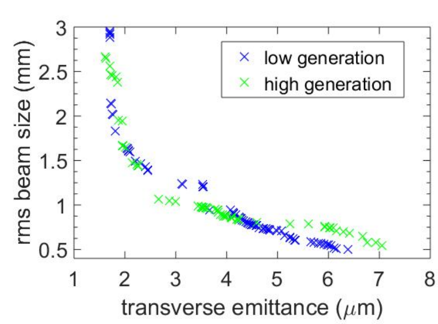

Figure 2: Pareto-front of MOGA optimization

Optimal transverse emittance are sensitively affected by the solenoid field and the gun phase, and they are also affected by the parameters of the beam itself. It could be convenient to drive an optimization code to minimize the

* Work is supported by China Postdoctoral Science Foundation (Grant No. 51627901) and Chinese Universities Scientific Fund (Contract WK2310000063)
† hezhg@ustc.edu.cn

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK123

emittance. MOGA is employed trading between transverse emittance and beam size. Rms Gaussian size σ_0, the gun injection phase, the solenoid field strength are set as knobs. Optimization results by both lower and higher generations are compared in Fig. 2. Since the results have been converged and can satisfy the requirement, one optimized solution with a lower emittance could be chosen from the higher generation. The spatial profile is a Gaussian distribution with σ_0=0.767 mm truncated at σ_0/r =1. Electron beam is injected in the gun at a phase of 24.9 degree off the zero crossing.

With a further tuning of solenoid field, the ultimate optimization result of electron beam (with solenoid field of 2400 Gauss) is presented in Fig. 3. The beam waist is located at 1.35 m downstream of the cathode with a minimum beam size σ_x=0.203 mm. The minimum transverse emittance could be 0.747 mm.mrad at the injector exit. A linear accelerator will be placed at the beam waist to rapidly boost the beam energy and freeze the emittance. The paramters of the electron source are listed in Table 2.

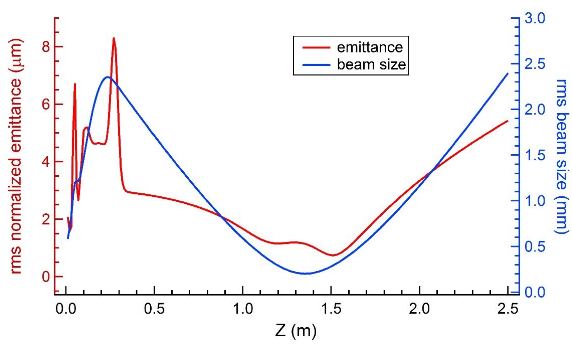

Figure 3: Evolution of transverse emittance and beam size of HALS beam

Table 2: The designed beam parameters

Parameter	Value
E	4.74 MeV
ΔE	38 keV (0.8%)
$\epsilon_{xn,rms}$	0.747 mm.mrad
$\sigma_{x,rms}$	0.203 mm
$\sigma_{z,rms}$	1.57 mm
I_{peak}	60 A
Q	1 nC

In Fig. 4, one can see the transverse and longitudinal profile of the electron beam at the injector exit.

The slice emittance and mismatch parameter of the beam are shown in Fig. 5. The profiles of beam current and energy spread are presented in Fig. 6.

It is simulatively proved that the physical design of the electron source can satisfy the requirement of HALS.

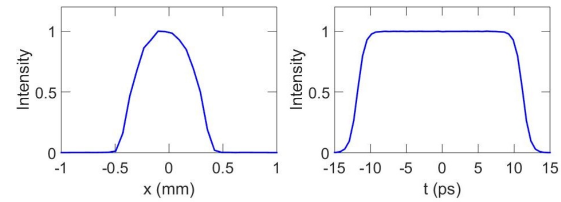

Figure 4: transverse (left) and longitudinal (right) beam pofile of the elctron source

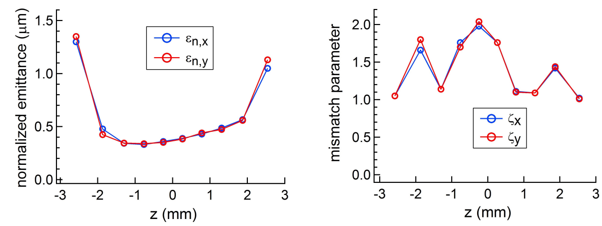

Figure 5: Slice emittance (left) and mismatch parameter (right)

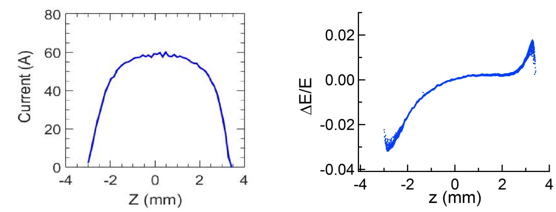

Figure 6: Beam current profile (left) and energy spread profile (right)

STUDY ON VELOCITY BUNCHING

Introduction on Velocity Bunching

Velocity bunching is a tool for compressing electron beams in high brightness photoinjector sources [4,5], which utilizes the velocity difference introduced by a traveling rf wave at a relatively low energy. The normal velocity bunching technique can achieve a compression factor of about 3 with the transverse emittance compensated, reported in reference [5]. The challenge of getting a higher compression factor is to preserve a symmetrical temporal distribution of the beam during such a dramatic compression process.

In the previous work, a brake-applied velocity bunching (BAVB) scheme [6] was proposed, in which a relatively short electron bunch was injected into a low-gradient compressor [7] at a deceleration phase, afterward slipped to an acceleration phase. Thanks to a larger phase slippage during a symmetric bunch compression, a compression factor of 19 for 800 pC bunch charge with full emittance compensation was realized by a -15 degree phase off zero crossing.

Study on the BAVB scheme of HALS beam

We are considering a velocity bunching scheme on the HALS electron source, with optimization of transverse emittance. When the HALS beam is injected in the compressor

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK123

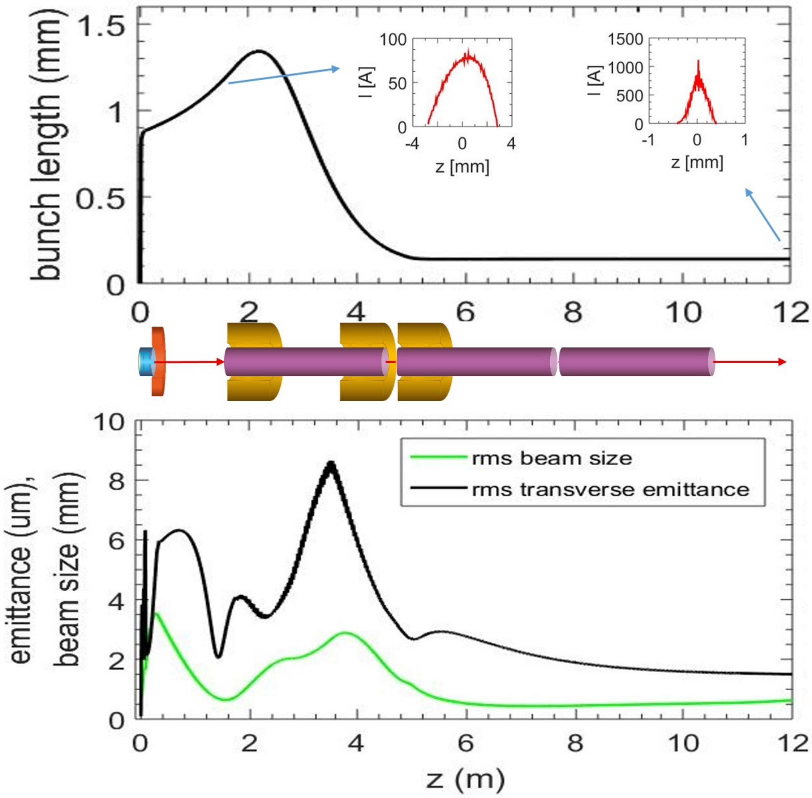

Figure 7: Simulation results of BAVB scheme. The top plot shows the rms bunch length evolution with current profiles before and after compression posted. The bottom plots are the transverse emittance and rms beam size.

at -10 degree phase, it is compressed to 0.15 mm in bunch length. The compression factor is above 10, however the transverse emittance is increased to 3.84 mm.mrad. Reducing the bunching factor cannot obtain a full emittance compensation as well. As the initial bunch length is so long that the intrinsic energy chirp is not linear and it is difficult to keep a linear compression process.

If the laser pulse length is reduced to 6.9 ps (uniform distribution with rms value of 3 ps), a more linear compression process is expected. By setting the injection phase at -10 degree, the electron beam could be compressed to 0.14 mm (compression factor of 9) with an emittance of 1.50 mm.mrad. Final kinetic energy is booted to 100 MeV. The simulation results are shown in Fig. 7. Although the emittance is not fully compensated, it satisfies the HALS requirement. It is certified that a symmetric longitudinal distribution has been conserved by viewing the current profile of the output. With a multi-stage magnetic compressor, a more compact and effective compression scheme could be realized.

It is notable that this velocity bunching scheme could be further optimized by a global optimization design. Besides for the HALS beam, a higher harmonic cavity [8] could be applied to remove the intrinsic non-linearity energy chirp and contribute to a shorter bunch.

CONCLUSION

We introduced the physical design of the high quality electron source for HALS. The initial design has fulfilled the performance criteria of the electron beam. Brake-applied velocity bunching scheme on the HALS electron source is considered. To satisfy the emittance requirement, a shorter laser pulse may be considered or a higher harmonic cavity would be applied.

REFERENCES

[1] K. Flottman, ASTRA user manual, `http://www.desy.de/~mpyflo/`

[2] K. Deb, et al., IEEE Trans. Evol. Comput. 6, 182 2002.

[3] F. Zhou, et al., PRST-AB 15, 090701 2012.

[4] L. Serafini and M. Ferrario, AIP Conf. Proc. 581, 87 2001.

[5] M. Ferrario, et al., Phys. Rev. Lett. 104, 054801 2010.

[6] R. Huang, et al., Nucl. Instrum. Methods Phys. Res. A 866, 65 2017.

[7] R. Huang, Z. He, W. Li, Q. Jia, Chin. Phys. C 38, 057004 2014.

[8] P. Emma, LCLS-TN-01-1, 2001.