POP EXPERIMENT FOR THE HB-HGHG SCHEME AT THE SXFEL

Kaishang Zhou[1, 2], Chao Feng[1], Haixiao Deng[1], and Dong Wang[1,†]
[1]Shanghai Institute of Applied Physics, CAS, Shanghai, China
[2]University of Chinese Academy of Sciences, Beijing, China

Abstract

High brightness, fully coherent and ultra-short free electron lasers (FELs) operating in the soft x-ray region are opening up new frontiers in many scientific fields. In this paper, we perform the design studies for the proof-of-principle experiment of the recently proposed HB-HGHG scheme at SXFEL test facility with a two-stage setup. The first stage of SXFEL is used for the generation of the coherent signal at 30th harmonic of the seed through the coherent harmonic generation process. Then this coherent signal is shifted ahead by the "fresh bunch" chicane of SXFEL and initiates the strong coherent radiation in the radiator of the second stage of SXFEL. The output properties have been compared with the conventional EEHG and the two-stage cascaded HGHG with the same harmonic up-conversion number.

INTRODUCTION

Most of the present X-ray Free electron lasers (FELs) around the world are operated in self-amplified spontaneous emission (SASE) mode [1, 2, 3]. However, the radiation pulse consists of many independent spikes because the process of amplification in SASE scheme starts from shot noise which is intrinsic in the accelerated electron beam [4]. Some advanced schemes are proposed to significantly improve the temporal coherence. Two paths are under rapid development: one is using a monochoromator that spectrally filters the SASE radiation at an early stage of amplification, e.g., Self-seeding scheme [5, 6, 7, 8], and another is using an external laser with good temporal and space coherence to seed the electron beam, e.g., High Gain Harmonic Generation (HGHG)[9], Echo-enabled Harmonic Generation (EEHG) [10,11] and Phase-merging Harmonic Generation (PEHG) [12,13] .

Recently, the High-brightness high gain harmonic generation (HB-HGHG) [14] scheme has been proposed to generate highly coherent and high brightness soft x-ray FEL which is also relying on the external seeding methods. The up-conversion harmonic number is mainly limited by the phase error amplification of seed laser and the brightness of the radiation pulse is confined by the length of the whole electron beam. In this paper, we perform the design studies for proof-of-principle experiment of HB-HGHG scheme at the SXFEL test facility with only one Chicane-Undulator (C-U) module.

THE PRINCIPLE OF HB-HGHG FEL

The schematic layout of HB-HGHG scheme is shown in Fig.1.The HB-HGHG FEL consists of one modulator, one dispersion section, one radiator and a series of C-U modules. The principle of the HB-HGHG scheme is shown as follows:

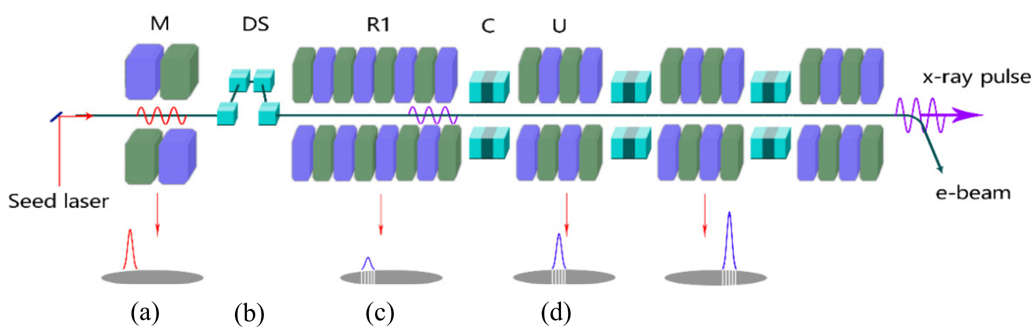

Figure 1: Schematic view of HB-HGHG scheme (a) Modulator (M), (b) Chicane (DS), (c) Short radiator (R1), (d) Chicane-Undulator (C-U) modules.

Firstly, a seed laser with short length compared to the whole electron beam is used to modulate the tail part of the electron beam in modulator (M), then the energy modulation of the tail part is converted into density modulation by a small dispersion section (DS), this tail part of electron beam is worked in coherent harmonic generation (CHG) regime, and then the electron beam will be sent into a short radiator (R1) to generate coherent signal. After that, the electron beam will be transported through a dispersion section, which is used to shift the coherent light to a fresh part of the electron beam and smear out the micro-bunching formed in the preceding stage. Finally, the coherent signal will be amplified by a series of C-U modules.

PROPOSAL EXPERIMENT AT THE SXFEL TEST FACILITY

The SXFEL test facility is initially designed to test the

† wangdong@sinap.ac.cn

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principle of two-stage cascaded HGHG scheme and conventional EEHG scheme, which consists of enough modulators and dispersion sections. Without any hardware modification, it is can be used to test the principle of the HB-HGHG scheme. To effectively suppress the micro-bunching instability, a seed laser with high power is generally needed. The up-conversion harmonic number is also 30 in this design which is the same as the initially designed two-stage cascaded HGHG (6x5) and conventional EEHG (30) [15]. Thus we can compare the simulation results between HB-HGHG and the cascaded HGHG and EEHG.

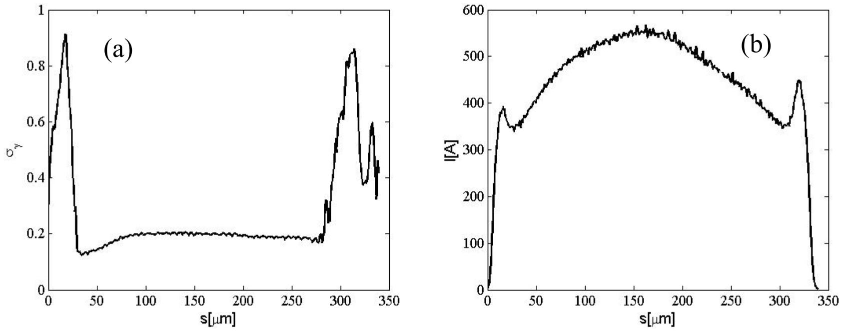

Figure 2: The output electron beam from elegant (a) energy spread, and (b) current profile.

Table 1: Main Parameters of SXFEL Test Facility

Electron Beam	
Beam energy	0.84Gev
Peak current	500A
Normalized emittance	1mm · mrad
Slice energy spread	102keV
Bunch length(FWHM)	1ps
Harmonic number	30th
Seed laser	
Seed wavelength	265nm
Pulse length(FWHM)	100fs
Seed powers	2.87GW
Rayleigh length	2.95m
Modulator	
Modulator period/cm	8cm
Modulator period numbers	20
Dispersion section	
Chicane strengths	3.3um
Radiator	
Radiator segment/m	3m
Period/cm	2.35cm
Radiation wavelength/nm	8.83nm

The nominal parameters used for this simulation are listed in Table 1. The energy of the electron beam is840MeV, the slice energy spread is 102keV and length of the electron beam (FWHM) is 1ps while the length of the seed laser (FWHM) is 100fs.

START TO END SIMULATIONS

The simulation for the linac is performed by elegant. The simulation results are shown in Fig.2. The slice energy spread is about 102keV and the peak current is about 500A at the exit of the linac.

The FEL part was simulated with Genesis [16]. A UV seed laser at 265 nm with pulse duration 100fs (FWHM) and the peak power 2.87GW is used to interact with the electron beam in the Modulator which has 20 periods with length of 8cm each, during which the modulation deep is about 45 with respect to the initial energy spread 102keV. Then the dumped beam from modulator is sent through the dispersion section with R56 of 3.3um. This electron beam is sent into a short radiator with period of 2.35 cm. The 30^{th} harmonic bunching factor at the entrance of the short Radiator is over 4%. Fig. 3 shows the simulation results. The output radiation peak power from the first short radiator is about 12MW.

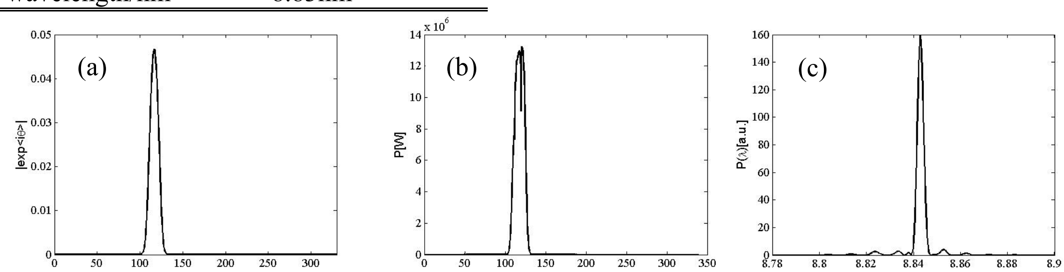

Figure 3: (a) Bunching factor at the entrance of short Radiator, (b) the output radiation peak power and (c) the output pulse spectrum from the short radiator.

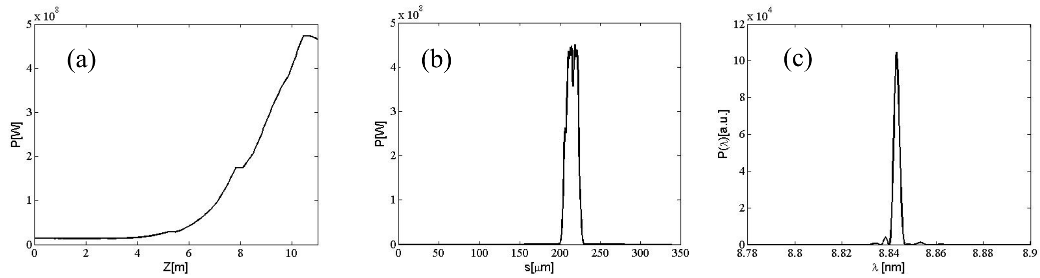

Figure 4: (a) the FEL gain curve, (b) the radiation peak power and (c) the output spectrum of the HB-HGHG scheme in one C-U module.

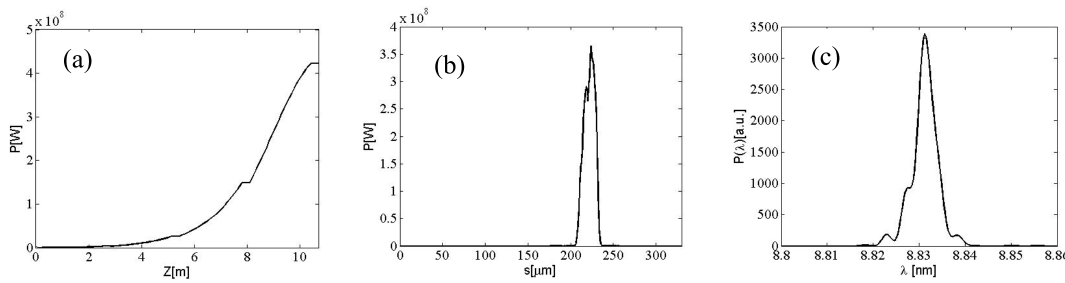

Figure 5: (a) the FEL gain curve, (b) the radiation peak power and (c) the output spectrum at the exit of the two-stage cascaded HGHG scheme.

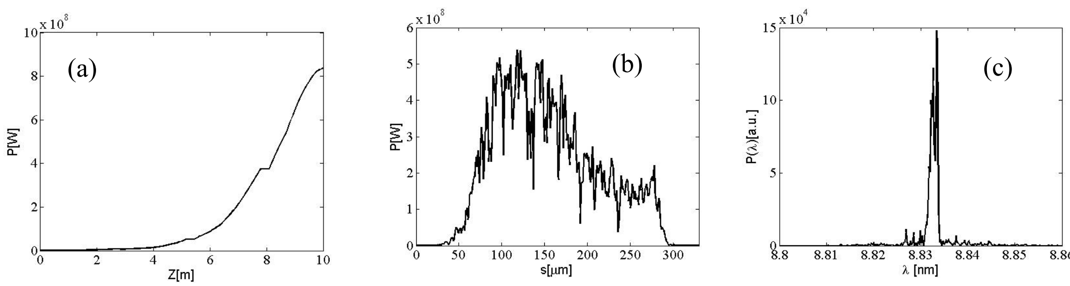

Figure 6: (a) the FEL gain curve, (b) the radiation peak power and (c) the output spectrum at the final Radiator of the conventional EEHG scheme.

This coherent radiation signal will be shifted to a fresh part of the electron beam by a chicane with R56 of 100 m, which is also large enough to smear out the micro-bunching formed in previous stage. The coherent signal will be amplified in the long undulator section. The gain curve, spectrum and the peak power are shown in Fig.4. The output peak power is about 400MW from the long radiator.

To compare with two-stage cascaded HGHG and conventional EEHG scheme, we have also carry out the numerical simulations with the electron beam parameters listed in Table1. For the two-stage cascaded HGHG, the Rayleigh length of seed laser is the same with HB-HGHG. The only different is that the peak power of the seed laser. The FEL gain curve, radiation peak power and the output spectrum at the exit of second Radiator are shown in Fig.5, respectively.

One can find that the saturation power of the two-stage cascaded-HGHG scheme is almost the same as that of the HB-HGHG. However, the spectrum band-width of the two-stage cascaded HGHG is much wider than the HB-HGHG. The reason is that the micro-bunching instability is more serious in two-stage cascaded HGHG which has two large dispersive sections while the proposed HB-HGHG scheme has only one small dispersive section.

For the EEHG case, the length of seed lasers used in the two modulators can fully cover the whole electron beam. The final FEL gain curve, radiation peak power and the output spectrum at the exit of the Radiator are shown is Fig.6, respectively.

The peak power of the radiation pulse is also at the same level. The output spectrum of radiation pulse has few spikes, however, this may not be true, which may just be caused by the numerical noise in the simulation process by R_{56}s.

CONCLUSION

In conclusion，we have proposed an experiment to test the principle of the HB-HGHG scheme. Using the SXFEL test facility parameters, the numerical Start to end simula-

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tion shows that the proposed HB-HGHG FEL can generate 8.8 nm highly coherent soft x-ray pulse with peak power over 400MW, which is comparable with the two-stage cascaded HGHG and EEHG schemes. One advantage of the HB-HGHG is that the peak power can be further amplified by orders of magnitude by using more C-U modules. This kind of light source would allow one to perform many challenging experiments which require narrow bandwidth and high brightness soft x-ray radiation pulses.

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