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PROOF-OF-PRINCIPLE EXPERIMENT DESIGN FOR PEHG-FEL IN SXFEL USER FACILITY

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Abstract

In this paper, we demonstrate a proof-of-principle experimental design for phase-merging enhanced harmonic generation (PEHG) free electron laser (FEL) in Shanghai Soft X-ray Free Electron Laser (SXFEL) user facility. The simulation results indicate that, taking advantage of the beam switchyard, the normal modulator and the seeded FEL line in SXFEL user facility, together with an oblique incident seed laser, we can perform the phase-merging effect in PEHG and finally get an 8.86 nm FEL radiation through the undulator, which is the 30th harmonic of the seed laser.

INTRODUCTION

High-gain seeded FELs [1–4] have got many progresses in recent years. They can produce stable and fully coherent FEL radiation pulses through UV to x-ray wavelength regime. The radiation power and phase can be particularly manipulated to satisfy certain unique experimental needs. The radiation pulses can also be well synchronized to the external seed laser to perform pump-probe experiments. There are several high-gain seeded-FEL schemes which have been proposed and experimentally-demonstrated worldwide, for example the High-Gain Harmonic Generation (HGHG) FEL and the Echo-Enabled Harmonic Generation (EEHG) FEL. The HGHG and EEHG are basically fulfilled by manipulating the electron beam in the longitudinal phase space. Recently, another high-gain seeded FEL scheme termed as phase-merging enhanced harmonic generation (PEHG) [5,6] has been proposed, which takes advantage of both the transverse and longitudinal phase space manipulation, and has the ability to further improve the frequency up-conversion efficiency of harmonic generation FEL.

Generally, PEHG needs a dogleg to introduce transverse dispersion into the electron beam, a straight incident seed laser interacting with the electron beam in a transverse gradient undulator (TGU) [7] to perform both the energy modulation effect and the phase-merging effect, as the schematic layout shown in Fig. 1 (a). Later study indicates that using a wavefront tilted seed laser in a conventional modulator can also perform the phase-merging effect in PEHG [8], as the scheme in Fig. 1 (b) shows. The wavefront tilted seed laser can be obtained by oblique incidence of the seed laser, and the normal modulator will be easy to implement in a seeded FEL facility.

The SXFEL user facility is upgraded from the SXFEL test facility [9]. It will deliver two photon beam lines to the users. The SASE FEL line will be straight forward, and the seeded FEL line will get the electron beam through a beam switchyard. In this work, we will give a proof-of-principle experiment design for PEHG-FEL in the seeded FEL line in SXFEL user facility, based on the scheme shown in Fig. 1(b).

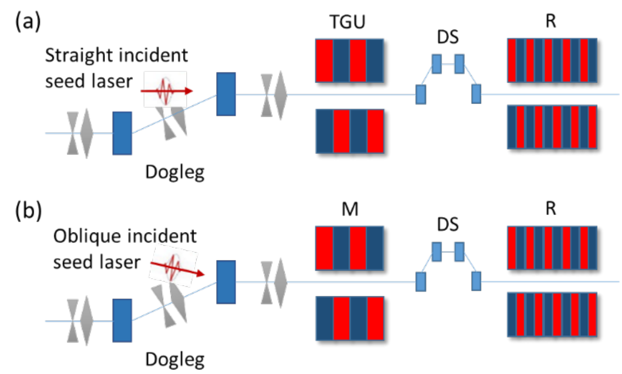

Figure 1: Two different PEHG schemes.

MAIN PARAMETERS AND FEL SIMULATION RESULTS

The schematic layout of SXFEL user facility is shown in Fig. 2. It consists of a linac which can provide electron beam with the energy up to 1.5 GeV, and two FEL beam lines which will be delivered to the users. The beam switchyard is used to distribute the electron beam to the FEL beam lines separately. In the seeded FEL beam line, there will be several modulators and dispersion sections (DS) to conduct the cascaded EEHG and HGHG in the future, and the magnetic lattice in front of the seeded FEL beam line will be dogleg-alike, which can be used to introduce a transverse dispersion into the electron beam. Hence the configuration of the SXFEL user facility is suitable for the PEHG-FEL experiment. The main parameters used in the experimental design is summarized in Table 1. The parameters are optimized based on the standard setup of the machine, without dramatic change to its original design.

With the parameters shown in Table 1, we carry out the electron beam simulation and the FEL simulation. Currently, we use an ideal electron beam in simulation to demonstrate the possible performance of the experiment. A 1.4 GeV electron beam is obtained in the linac. After passing through the switchyard, the electron beam gets an 0.5 m transverse dispersion. Then an oblique incident seed laser with 0.15 mrad incidence angle is going to interact with the electron beam in the modulator. During this process, the electron beam will undergo both an energy modulation effect and a phase-merging effect. And finally the DS will help form the density modulation in the electron beam. If every procedure goes

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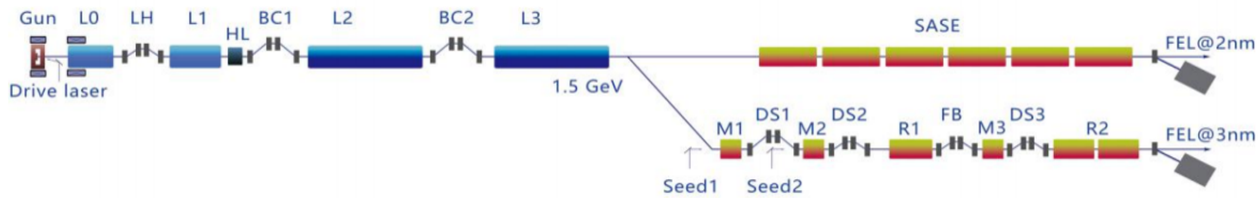


Figure 2: The schematic layout of the SXFEL user facility.

Table 1: Main Parameters

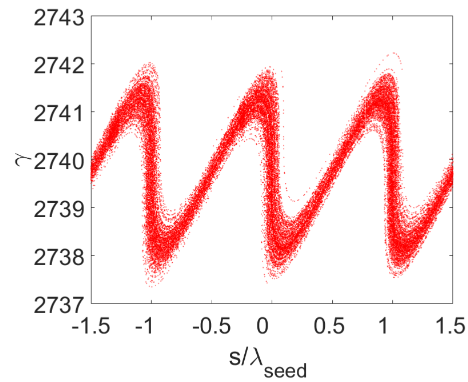
Parameters	Value
Beam energy (GeV)	1.4
Slice energy spread (%)	0.01
Normalized emittance (μm·rad)	0.7
Charge (pC)	500
Peak current (A)	700
Seed laser wavelength (nm)	266
Seed laser incident angle (mrad)	0.15
Transverse dispersion of switchyard (m)	0.5
Modulator: $N_p \times \lambda_u$ (m)	20×0.055
R_{56} of DS (mm):	0.075
Radiator: $N_s \times N_p \times \lambda_u$ (m)	$6 \times 100 \times 0.03$
FEL wavelength (nm)	8.87

well, the longitudinal phase space of the electron beam at the entrance of the radiator will be like Fig. 3 (right). We can see that the PEHG effect has been introduced into the electron beam. For comparison purpose, we also illustrate in Fig. 3 (top) a electron beam phase space with the seed laser straight incident, which is a typical HGHG effect.

The current profile and the FEL simulation results for PEHG-FEL are shown in Fig. 4. The FEL wavelength is 8.87 nm, which is the 30th harmonic of the seed laser. The peak power is about 800 MW and the pulse energy is about 200 μJ. The bandwidth is about 1.3×10^{-4}. We also carry out the FEL simulation for the electron beam with straight incident seed laser. The pulse energy and spectra comparison for FEL radiation results with 0.15 mrad incident angle and straight incident are illustrated in Fig. 5.The pulse energy of the FEL radiation for the straight incident seed laser is about 50 μJ. The FEL bandwidth is about 0.22%. One can find that the power of the PEHG-FEL is gaining faster, and the spectra of PEHG-FEL is almost Fourier-transform-limited. That's because the bunching of 30th harmonic in PEHG-FEL is still strong, actually the bunching factor for 30th harmonic in PEHG-FEL is about 0.08, while the 30th harmonic bunching is just at the noise level when the seed laser is straight incident.

CONCLUSIONS AND DISCUSSIONS

In conclusion, we demonstrate a preliminary proof-of-principle experiment design for PEHG-FEL in SXFEL user facility. By implementing an oblique incident seed laser,



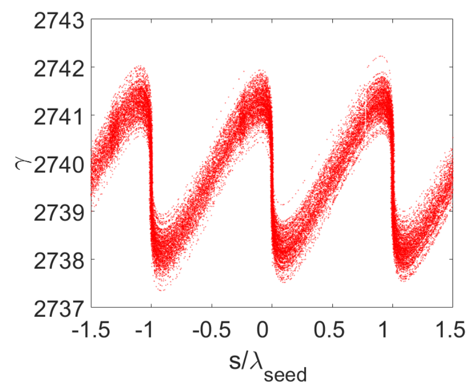


Figure 3: Typical HGHG effect with straight incident seed laser (top) and PEHG effect with oblique incident seed laser (bottom).

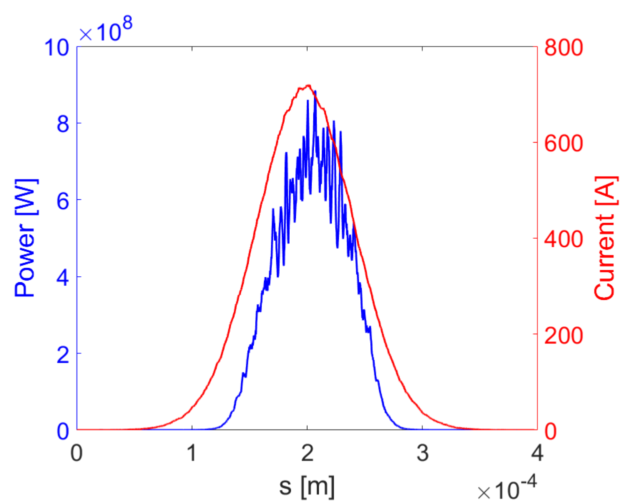


Figure 4: PEHG-FEL radiation.

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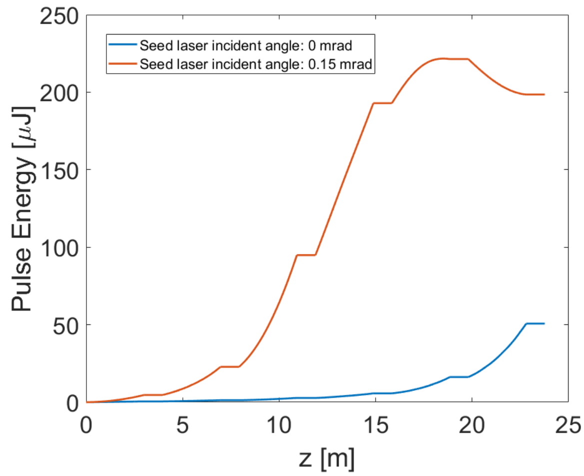
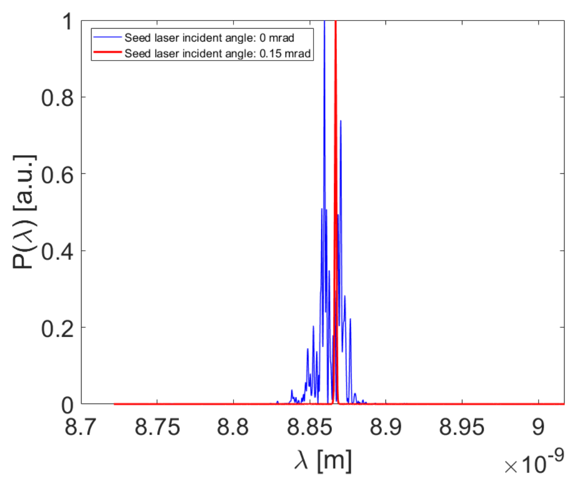


(a) Pulse Energy



(b) Sepctra

Figure 5: The pulse energy (a) and spectra (b) comparison for FEL radiation results with 0.15*mrad* incident angle and straight incident.

together with the switchyard, the modulator and the DS, we can achieve the PEHG effect in the seeded FEL line in SXFEL user facility, without dramatic change to its setups and configurations. The simulation results indicate that a fully coherent 800 MW PEHG-FEL radiation can be obtained.

The seed laser incident angle in our experiment design is of great importance. The seed laser system needs the capability of fine tuning of the incident angle. The tuning accuracy needs to be about 0.01 mrad, and also the incident angle need to be very stable. In addition, this set up can be replaced with a normal incident seed laser and a TGU, which are also in consideration. The PEHG-FEL may be very sensitive to both the electron beam energy fluctuation and the seed laser incident angle. And the power fluctuation may be very large. On that circumstances, the fully coherent spectra maybe a good way to evaluate the PEHG-FEL performance.

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