ECHO-ENABLED HARMONIC GENERATION BASED ON HEFEI STORAGE RING

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Abstract

Hefei Light Source (HLS) is undergoing an upgrade project to enhance the performance. As a possibility, we consider implementation of the echo-enabled harmonic generation (EEHG) technique to generate coherent free electron laser in VUV to soft x-ray, which is the dominate region for the users at HLS. The difference of this work to other similar research is that we use the whole ring as the first dispersive section and an optical klystron as the second one. In this case, only one modulator is needed. The preliminary design and simulation are presented.

INTRODUCTION

HLS is a dedicated second generation VUV light source with a circumference of 66.13 m. Its main body is composed of 800MeV electron storage ring, 200MeV linac and beam transfer line. In recent years, HLS is undergoing an upgrade project mainly to decrease the beam emittance and increase the number and length of the straight section. The lattice of storage ring after upgrade is shown in Fig.1.

Several ways have been proposed to produce FEL radiation based on storage ring. One of them is the coherent harmonic generation (CHG) technique [1, 2] which has been experimented at many labs including HLS [3]. The EEHG scheme [4, 5] which has been shown to be more efficient comparing with some other seeding FEL schemes is another way, and its application at storage ring has been studied at DELTA [6] and SOLEIL [7]. However, they both implement the EEHG technique in part of their storage ring.

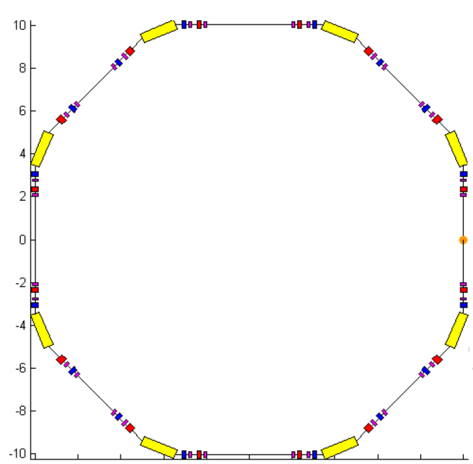


Figure 1: Lattice layout of Hefei Light Source.

In this proposal we consider EEHG as a possible upgrade in order to obtain FEL radiation in VUV region. Enlightened by D. Xiang, we intend to use the whole ring to provide the strong dispersion . In this case, only one modulator is required as which can play the role of the two modulators when the electrons pass the undulator in two adjacent turns. Therefore, the straight section can be saved for other purposes.

THEORY

Normally, the EEHG FEL consists of two modulators, two dispersive sections and one radiator. The first laser pulse modulates the electron energy sinusoidally in the first modulator, then the first chicane with a large R_{56} tilts the electrons phase space to separate energy bands. The electrons interact with another laser pulse in the second modulator and pass through the second chicane with a moderate R_{56} to generate a density distribution with a high harmonic content.

At HLS storage ring, we consider using the whole ring as the first dispersive section, whose momentum compaction factor is very low for obtaining a $R_{56}^{(1)}$ in the order of ~ mm. It can be given as

$$R_{56}^{1} = \alpha C \quad (1)$$

Where α is the momentum compaction factor and C is the circumference.

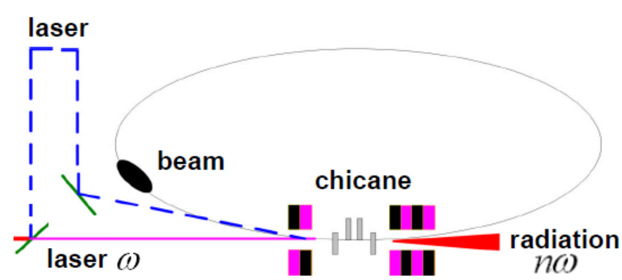


Figure 2: Schematic of the EEHG scheme at HLS.

Figure 2 shows the schematic of the EEHG at HLS. The seeding laser is split into two paths with a time separation. One laser interacts with the beam in the modulator, then the modulated beam travels through the ring one turn and separated energy bands are generated by the dispersion of the whole ring. The other laser is delayed to meet the electron beam and modulate the beam again in the modulator after one turn. After the chicane separated energy bands convert to separated current bands and significant bunching is achieved. The bunched beam finally generates intense coherent radiation in the radiator. Considering the repeat rates of the seeding laser, the electrons runs about a few kilo turns between every two FEL pulses and the beam structure is washed out with the help of synchrotron radiation damping.

The scheme is similar to those schemes of EEHG in the linac, except that here only one modulator is required. This scheme may significantly enhance the capability of HLS with minimal modifications to the existing ring configuration.

PRELIMINARY DESIGN AND SIMULATION RESULTS

As we do not expect to influence the synchrotron users at HLS, the design is based on the existing lattice and hardware, and the currently available electron beam parameters are used.

Firstly, we study the energy spread $\Delta\sigma_E$ introduced by Incoherent Synchrotron Radiation (ISR) when the electron bunch radiates in bending magnets. It can be calculated as [8],

$$\Delta\sigma_E^2\big|_{ISR} = \frac{55e^2hc}{48\sqrt{3}}\frac{L}{\rho^3}\gamma^7 \qquad (2)$$

Where h the Planck constant, c the light velocity, L the bend length and ρ the bending radius, γ the normalized energy. In the HLS case, L=1.7m, ρ=2.1645 m, so $\Delta\sigma_E$ =0.06σ_E. This diffusion may exceed the spacing of the two adjacent energy bands and thus smear the fine structure of EEHG FEL in the longitudinal phase space. So special consideration is given to the spacing of the two adjacent energy bands which is in the order of $(\pi/B_1)\sigma_E$.

Based on the thinking above, we roughly optimize a set of EEHG parameters as a priliminary research for practical design. We expect to achieve 40 nm FEL radiation from an 800 nm seed laser. According to the range of the momentum compaction factor that can be easily tuned, we choose A_1=3, $R_{56}^{(1)}$=9.758 mm , A_2=2.83, $R_{56}^{(2)}$=0.522 mm. Here, the momentum compaction factor is about 1.4×10^{-4}, which can be obtained by tuning the strength of the quadrupole. In this case, the spacing of the adjacent energy bands is about 155 keV and much larger than the energy spread growth caused by ISR.

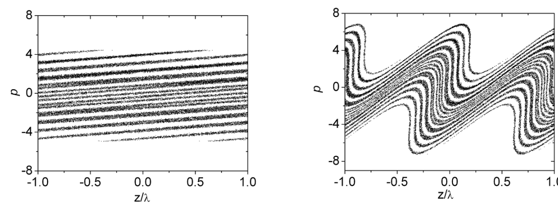
It is worth pointing out that the element R_{51} and R_{52} of the ring transmission matrix should be optimized carefully. In the EEHG FEL based on linac, it does not seems a problem because they are both zero for a 4-dipole chicane. But in this scheme, in order not to wash out the bunching, we may require the condition

$$R_{51}\sigma_x + R_{52}\sigma_x^{'} < \lambda_r / 20 \qquad (3)$$

to be satisfied, where λ_r is the wavelength of the harmonic.

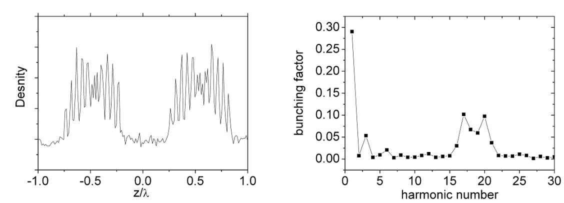
We have numerically simulated the bunching process of our EEHG scheme with ELEGANT [9]. Firstly, the high order effect of the ring is neglected and only the first order transmission matrix work. Figure 3 shows the longitudinal phase space after the two dispersive sections, and the density distribution and the bunching factor at the entrance of the radiator are given in Figure 4. From these results, one can find that the bunching at 20th harmonic is high enough.

Then we extend the transmission matrix to second order, and the longitudinal phase space after the first dispersive section is illustrated in Fig.5(a). The energy bands below the center energy become bending like a hyperbola, thus the bunching is degraded dramatically as shown in Fig.5(b). We examine the second order matrix and find that the matrix element T566 run up to about 30 m. In this case, the is comparable with . T566 can be minished by adjusting the strength of sextupole. This will be done in the future as the correction of chromaticity also should be considered.



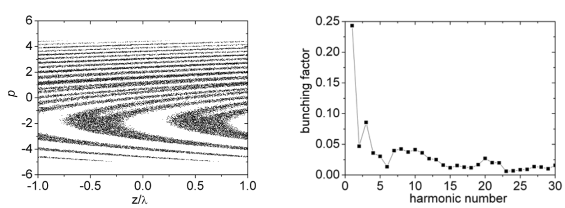
(a) (b)

Figure 3: Longitudinal phase space (a) after passing though the whole ring; (b) after the second modulator and passing though the small chicane.



(a) (b)

Figure 4: At the entrance of the radiator: (a) the desity distribution; (b) the bunching factor.



(a) (b)

Figure 5: Simulation results considering the second order effect: (a) longitudinal phase space after the passing though the whole ring; (b) the bunching factor at the entrance of the radiator.

SUMMARY

In this work, a method to generate coherent radiation in HLS storage ring using the EEHG scheme has been preliminarily designed and discussed. The distinguishing feature of this scheme is that we apply the whole ring as the strong dispersive section and thus only one modulator is needed. From the simulation results, we can find that the difficulties also come from here, such as the design of the low momentum compaction factor lattice, the optimization of the R_{51} and R_{52}, especially how to

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eliminate the second order effect and so on. In the future, we will try to overcome these difficulties more practically and more deeply, and these unfavorable effects will be taken into overall consideration.

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