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LATTICE DESIGN FOR THE REVERSIBLE SSMB*

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Abstract

Steady State Microbunching (SSMB) aiming at producing high average power radiation in the electron storage ring has been proposed by Ratner and Chao years ago. Reversible seeding scheme is one of the promising scenarios with less challenges on the storage ring lattice design. The key problem for reversible SSMB is the precise cancelation of the laser modulation which will allow producing turn-by-turn coherent radiation without spoiling the transverse emittances and energy spread. In this paper the lattice design for the microbunching generation and its cancelation will be presented. Also a whole ring multi-turn tracking based on transfer matrix will be shown.

INTRODUCTION

Electron storage ring based light source has achieved remarkable progresses which can produce extremely brilliant synchrotron radiation from infrared to hard X-ray [1, 2,3]. It gets high repetition rate but comparatively low peak brilliance or coherence comparing to linac based free electron laser (FEL). FEL provides high peak power coherent radiation while at low repetition rate which limits its average power [4].

To approach high average power radiation, steady-state-micro-bunch (SSMB) had been proposed since 2010 [5]. SSMB is based on an electron storage ring which is much more mature comparing to the energy recovery linac (ERL), the latter one is also a candidate for high average power radiation provider yet under developing [6]. When SSMB length closes to the radiation wavelength, coherent radiation will be produced and radiation power will be orders of magnitude higher, together with high repetition rate, high average power radiation will be produced which has some important industry applications such as EUV lithography.

There are several scenarios to produce SSMB [7]. This paper is focused on the reversible SSMB scheme for which micro-bunch is only produced within the radiator after the modulation and then restored to the normal state by a reverse modulation. The key point of reversible seeding module is that cancellation of two modulators should be perfectly realized which will allow producing turn-by-turn coherent radiation without spoiling the transverse emittances and energy spread. Linear and nonlinear parts of the beam dynamics between two modulators is studied bellow. Also a whole ring multi-turn tracking results are shown.

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ANGULAR DISPERSION ENHANCED MICROBUNCHING

For reversible SSMB, perfect cancellation of two modulators is important to realize turn-by-turn coherent radiation. Laser induced energy modulation should as weak as possible to confine the modulation to the linear region. The angular dispersion enhanced microbunching [8] is a suitable method to produce high harmonic by a very weak modulate if an electron beam gets very small vertical emittance which is naturally preserved in an electron storage ring. The layout of this scheme is similar to a conventional CHG scheme, as shown in Fig. 1. However, a magnetic dipole (B) is added upstream of the modulator, and the magnetic chicane in the conventional CHG is replaced by a dogleg that consists of two dipole magnets of opposite polarity as the dispersion section (D). The first dipole is used to introduce an angular dispersion into the electron beam. Then seed laser pulse at optical wavelength is employed to interact with the electron beam in the modulator to introduce a small energy modulation. After that, the energy modulation is converted into density modulation by the dogleg. The dispersive properties of the first dipole and the dogleg allow, if the parameters are chosen properly, the full compensation of the initial beam energy spread to produce very sharp micro-bunches at the EUV wavelength. This kind of electron beam would help to initiate intense coherent radiation at EUV wavelength in the following radiator. The proposed scheme can be inserted in a long drift section of the ring. The transverse dispersion generated by the dogleg can be fully compensated by another reversed dogleg (D*) after the radiator. By using a reversed modulator section, it is possible to fully recover the properties of the electron beam as shown in Fig. 1. This technique can make full use of the low emittance of the electron beams from storage ring while effectively mitigating the detrimental effect from the large energy spread in the meantime.

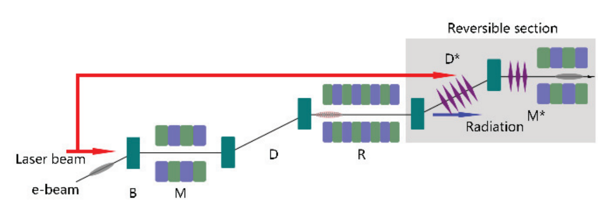

Figure 1: Layout of the reversible SSMB.

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REVERSE BEAM LINE SETTING

Thera are 5 quadrupoles in (D*) in Fig. 1, by which negative drift transport can be generated between two bends. The negative drift dogleg produces opposite η and ξ to the first dogleg (D). In case of without considering nonlinear effects, beam can be fully recovered. However when we approach longitudinal beam dynamics to 10nm scale, the nonlinear effects become significant. Among them, T511 and T512 are the most prominent terms, which can be expressed by the following：

$$T_{511} \approx -\frac{\gamma_0}{4}\int_0^L \gamma(s)ds \qquad (1)$$

$$T_{512} = T_{521} \approx -\frac{\gamma_0}{8}(\beta(L)-\beta_0) \qquad (2)$$

Where β and γ are the twiss parameters in vertical plane. Unfortunately, the angular-dispersion-enhanced-microbunching is only effective when vertical angular divergence of the beam is sufficient small, which not only requires a small vertical emittance but also requires large vertical beta and zero vertical alpha function at the entrance of the (B). With this constraint, the way to reduce T511 and T512 by optimizing twiss parameters is limited.

So sextupoles are added in the beam line to control the nonlinear effects as shown in Fig. 2. The optimized result in Fig. 3. shows that RMS energy spread increment after energy modulation and reverse energy modulation is $\Delta\sigma_E/\sigma_E = 1.6e-5$ (The initial RMS energy spread before energy modulation is $\sigma_E = 3.9e-4$), which is about an order lower than that without sextupoles.

The first modulator is following (B) where η’ is a matched non-zero value to achieve micro-bunch at the radiator. Which may cause unequal η at the two modulators. When performing energy modulation at the place where η’ or η is not zero as show in Fig. 2, the vertical emittance will be disturbed. The imperfect energy recovery may result an emittance increment. With initial vertical emittance $\varepsilon_y = 2pm \cdot rad$, a single passage of the beam line may case $\Delta\varepsilon_y/\varepsilon_y = 1.0e-2$, which is a nontrivial number. However we will show latter in the multi-turn tracking that only a small fraction of the disturbance can be accumulated.

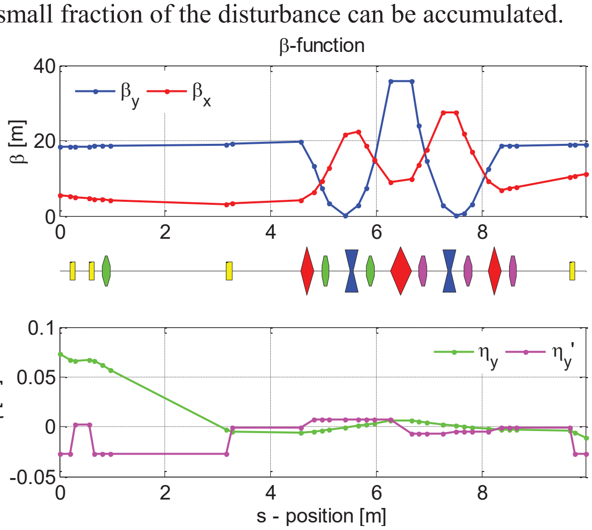

Figure 2: Reverse beam line setting.

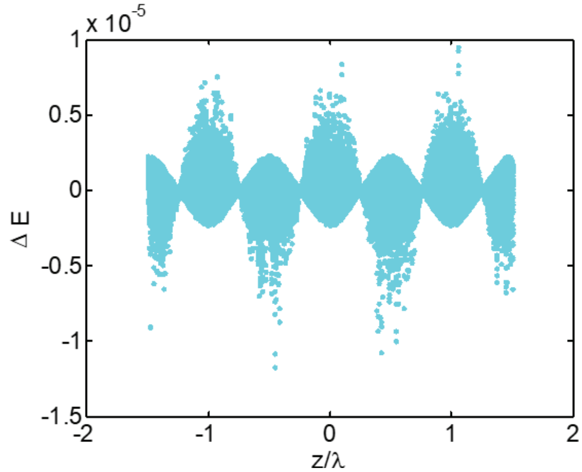

Figure 3: Energy change after two modulaters.

MULTI-TURN TRACKING

The increment of the vertical emittance is 1.0e-2 in a single pass tracking, which can be expressed as

$$\frac{\Delta\varepsilon_y}{\varepsilon_y} \propto \frac{(y'+\Delta y\prime)^2-y'^2}{y'^2} = \frac{2y'\Delta y'}{y'^2} + \frac{\Delta y'^2}{y'^2} \qquad (3)$$

The first term does not have a cumulative effect of the turn by turn while only the second term can be accumulated because the beam is Gaussian distribution. The following multi-turn tracking results can confirm this.

An actual ring has not been designed yet, so a 4×4 transfer matrix in (x,x’,y,y’) phase space is used instead of the ring for tracking. We assume that the exit of the reverse modulation point (P1) is the starting point of the ring and the entrance of the modulation point (P2) is the end point of ring. The appropriate Twiss parameters are selected at P1 and P2 to match the SSMB insertion. Also, the pertinent phase advance is chosen. With these parameters, the transfer matrix of this ring will be obtained. Other parameters of this hypothetical ring are listed in Table 1. The movements of beam are tracked by using Elegant [9] with second order transport effects taken into account for the SSMB insertion.

Table 1: Main Parameters in Hypothetical SSMB Ring

Parameters	Value
Energy / GeV	0.4
Laser wavelength / nm	260
Horizontal emittance / pm rad	500
Vertical emittance / pm rad	2
Momentum compaction factor	1e-5
Natural energy spread	3.9×10–4
Damping Time / ms	65.2/76.9/35.5

The multi-turn tracking steps are described as follows.

1. Random initial beam in P1 with 11 wavelengths in the longitudinal direction.

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2. Let this beam pass through the transfer matrix (from P1 to P2), and then the radiation damping must be included.
3. Add the vertical dispersion η_2 and η_2' into the beam.
4. Simulate tracking from P2 to P1 with modulation and reverse modulation.
5. After reverse modulation in P1, add the vertical dispersion η_1 and η_1' into the beam to make sure the η and η' are zero.
6. Return to the second step for multi-turn tracking.

The tracking results are shown in Fig. 4.

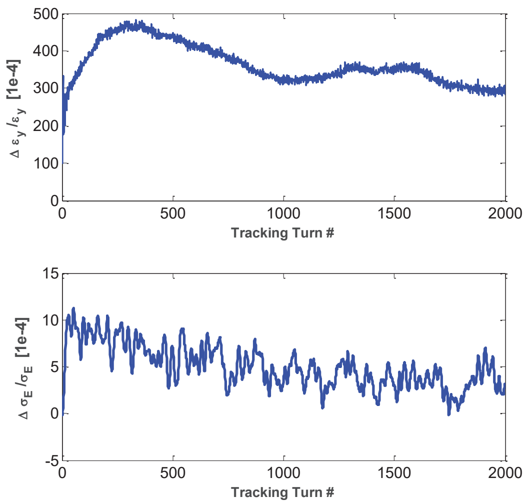

Figure 4: The growth of vertical emittance and energy spread.

Modulations are done in the vertical plane and the horizontal is an uncorrelated plane, so we are not concerned with changes in horizontal. The growth of vertical emittance and RMS energy spread is stable after 2000 turns.

CONCLUSION

Reversible SSMB is one of the promising scenarios to produce high average power coherent synchrotron radiation. With angular dispersion enhanced microbunching scheme high harmonic can be produced by a very weak modulate, with this advantage the nonlinear effects can be well controlled and the beam can be precisely kicked back. Yet a real beam tracking is needed to confirm the emittance and energy grow up.

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