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STRONG FOCUSING LATTICE DESIGN FOR SSMB

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Abstract

A storage ring applicable for SSMB operation is a critical part of a high average power SSMB EUV light source. A lattice for SSMB based on longitudinal strong focusing is under design in Tsinghua University. To generate and maintain micro-bunching in a storage ring in this scenario, the momentum compaction has to be small. A lattice with low momentum compaction factor is presented in this work. The lattice of the current design consists of two MBA cells with isochronous unit cells to minimize local and global momentum compaction, and two straight sections for insertion devices. The design energy of the ring is 400MeV and the circumference is 94 meters. Nonlinear effects such as higher order momentum compactions will continue to be optimized.

INTRODUCTION

Deep ultraviolet lithography, which is the current technology used to produce microchip, begins to reach its limit

To develop microchips with etched circuit lines smaller than 0.1um, new technology is needed. Extreme ultraviolet lithography is a next generation of lithography technology and the wavelength is expected to be 13.5nm, while DUV's wavelength is 193nm or 248nm. A microprocessor made with the EUVL technology would be a hundred times more powerful than today's. SSMB (Steady State Micro-Bunching) is a promising scheme for high average power EUV light sources.

When electrons are grouped into micro bunches spaced at the wavelength of desired radiated light, the radiation process is coherent and the brightness of the resulting light is orders of magnitude higher than that of an equivalent incoherent light source. In a linac based light source such as conventional FELs, the electron bunch passes through the radiator once, leading to low duty cycles, and thus the average radiation power is limited. In the contrast, storage rings offer a much higher repetition rate and potentially produce much higher average radiation power. In this work, our attempts at designing a storage ring applicable for SSMB operation are presented.

LOW MOMENTUM COMPACTION LATTICE

Based on conventional formulas, the bunch length in a storage ring is related to momentum compaction factor and RF parameters.

$$\sigma_z = \frac{\eta\sigma_\delta C}{2\pi\nu_s} = \frac{(\alpha_c - 1/\gamma^2)\sigma_\delta C}{2\pi\nu_s}, \qquad (1)$$

where α_c is the momentum compaction factor, γ is the Lorentz factor, and ν_s is the synchrotron tune. Synchrotron tune depends on RF parameters and momentum compaction factor [4]:

$$\nu_s = \sqrt{\frac{heV|\eta\,\mathrm{co}\qquad {}_s|}{2\pi\beta^2 E}}, \qquad (2)$$

where h is the harmonic number, V is the RF voltage and ϕ_s is the synchronous phase. According to these formulas, equilibrium bunch length is proportional to the square root of slip factor, and by reducing momentum compaction, the bunch length can be shortened to realize sustained micro bunching.

Momentum compaction factor is directly defined as the integral of the dispersion function.

$$\alpha_c = \frac{1}{C}\int \frac{\eta_x}{\rho}\,\mathrm{d}s. \qquad (3)$$

To achieve low momentum compaction, the most straightforward way to do is to make the dispersion in bending magnets cancel out. Figure 1 shows a conventional double bend achromat. The strengths of the quadrupole magnets between the two dipole magnets are chosen such that the dispersion function is symmetric about the central quadrupole. To achieve low momentum compaction, the strength of the central quadrupole can be tuned to introduce asymmetry into the dispersion function. As is shown in Fig.2, the dispersion function in the two bending magnets is opposite in sign. As a result, the compaction factor can be small.

Figure 3 shows the layout of the first version of the SSMB lattice. The calculation of the beta function is done with Elegant.[1] The lattice consists of four cells. Each cell consists of two dipole magnets with cancelling dispersion function. Each pair of the cells has symmetrical optical functions so two cells form a four bend achromat with the straight sections on both ends free of dispersion. The dispersion free sections can accommodate equipment like RF cavity or undulator.

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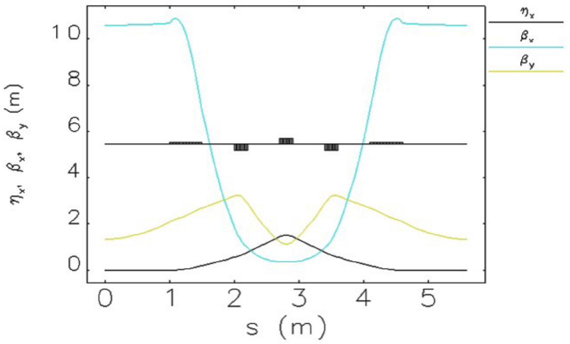

Figure 1: A conventional DBA structure.

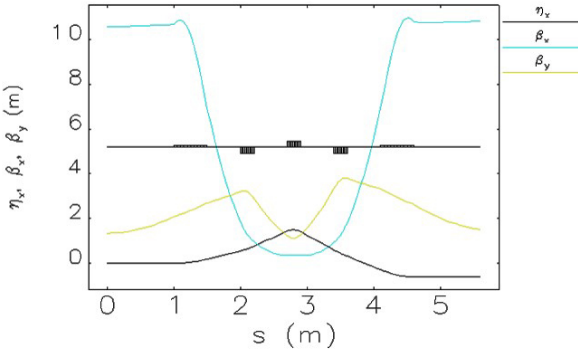

Figure 2: A DBA with the central quadrupole tuned to introduce asymmetricity to reduce momentum. compaction.

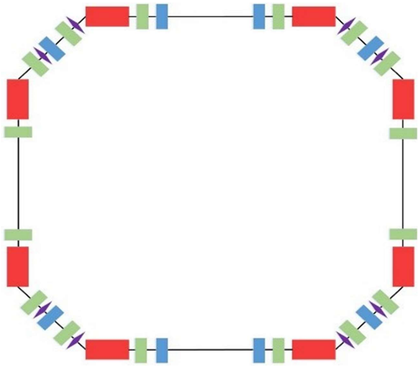

Figure 3: Layout of the lattice.

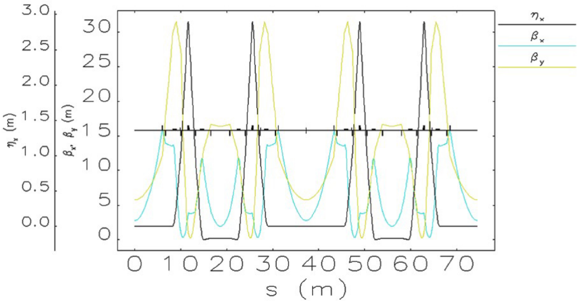

Figure 4: Optical function of the lattice.

The momentum compaction factor of the lattice is optimized to be 1e-6 and the natural energy spread is 3.5e-4, so the bunch length should be less than 1um assuming the synchrotron tune to be about 0.1. It's possible to modulate a longer bunch to several smaller bunch in this ring with a 1um modulator. However, further simulation indicates that this is not the case. In deriving the bunch length formula above, it's neglected that the path length of each electron in a bunch is fluctuating by photon emission. The magnitude of this fluctuation depends on local parameters of the ring. Consider an electron that moves along the design orbit, after it emits a photon and then travels to another location in the ring. Assuming the derivatives of dispersion functions and beta functions to be zero at both locations, to simplify the algebra, the orbit change due to photon emission is ([2]):

$$\Delta z = -\frac{\varepsilon}{E}\left(\Delta R_{56} + \frac{\eta_1\eta_2}{\sqrt{\beta_1\beta_2}}\sin\psi\right). \qquad (4)$$

The bunch length after taking this effect into account is ([2]):

$$\sigma_z^2 = \sigma_{z,sands}^2 + \delta_\delta^2\left(\Delta R_{56}^2 + \frac{\eta_1^2\eta_2^2}{2\beta_1\beta_2}\right). \qquad (5)$$

As a result, when the momentum compaction is reduced, the second term dominates. Figure 5 and figure 6 shows the comparison between 1um bunch modulations with and without photon emission. With photon emission, the structure of the bunch is smeared and micro bunching is unsustainable.

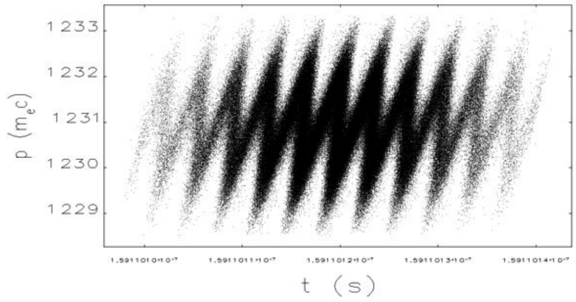

Figure 5: Bunch modulation without photon emission [3].

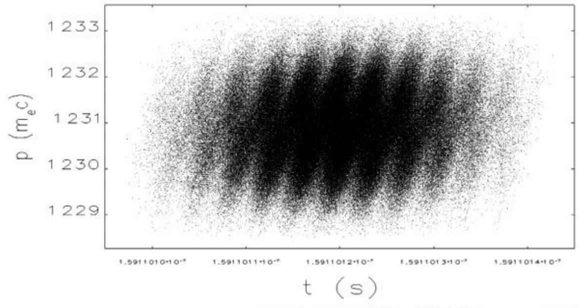

Figure 6: Bunch modulation with photon emission [3].

The possible solution to this problem is to reduce the bending angle of the dipole magnets. By reducing the bending angle, synchrotron radiation is weaker and both the R56 and the dispersion function are smaller. As a result, the second term in equation 3 is so small that the first term dominates again.

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ISOCHRONOUS CELL

To study the effect of quantum excitation and find a suitable lattice for SSMB, a new test cell is designed. The layout and optical functions of the test cell are shown in figure 7.

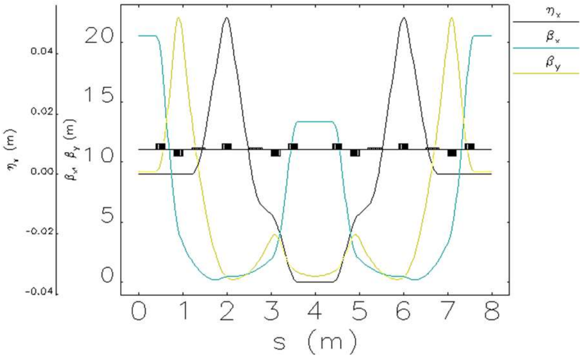

Figure 7: Layout and optical functions of the new cell.

The length of the bending magnet is set to be 0.3m, while the bending angle can be changed to create cells with different dispersion function. The profile of dispersion remains the same when changing the bending angle, so R56 of the cell remains small. The cell is an achromatic structure so both ends of the cell is free of dispersion, which can accommodate an RF cavity for modulation. With 1nm modulation, the bending angle of the dipoles is varied from 0.5° to 9°. The bunch lengthening effect is plotted in Fig. 8. With increasing bending angle, the bunch length increases quartically. For our final EUV cell, we expect the micro bunches to be a few nm long, so the bunch lengthening effect should be kept within 1nm. As a result, the total bending angle of an isochronous cell should not exceed 30°.

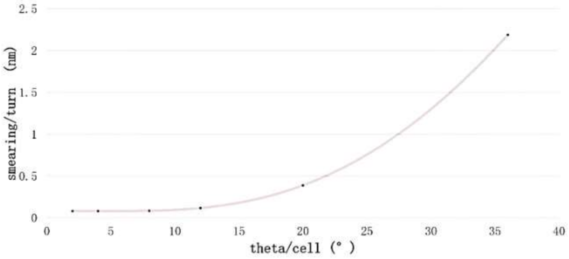

Figure 8: Bunch lengthening effect and the bending angle of the cell [3].

The current lattice layout is shown in Fig. 9-11. Each arc consists of 12 isochronous cells. The bending angle of the dipole magnets is 13°. Unlike the test cell, the current cell is not achromatic, so the R56 of each dipole can be optimized to be zero and each of the dipoles is isochronous. A dispersion suppression cell is designed to provide a 10m dispersion free section for future upgrade such as a strong longitudinal focusing scheme. The dispersion suppression cell consists of a half isochronous cell and a small corrector magnet whose bending angle is -1 °. The momentum compaction factor is 1e-6 and the second order momentum compaction factor is 0.025. Nonlinear momentum compaction becomes the dominant limitation for bunch length shortening when further reducing the linear compaction factor, so more optimization is needed by using sextupoles.

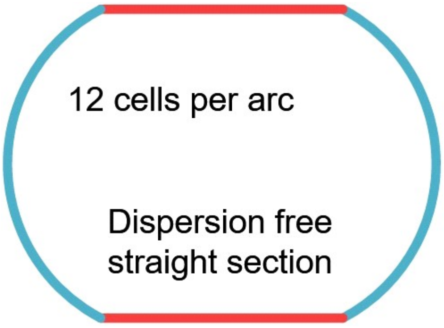

Figure 9: The layout of the current lattice.

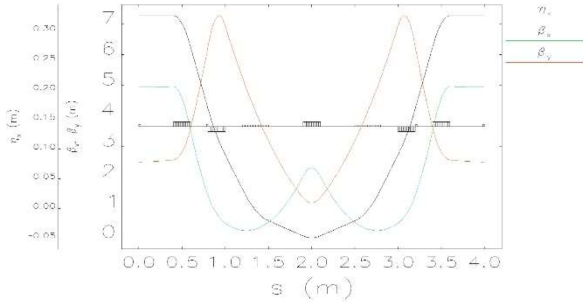

Figure 10: Layout and optical functions of the current isochronous cell.

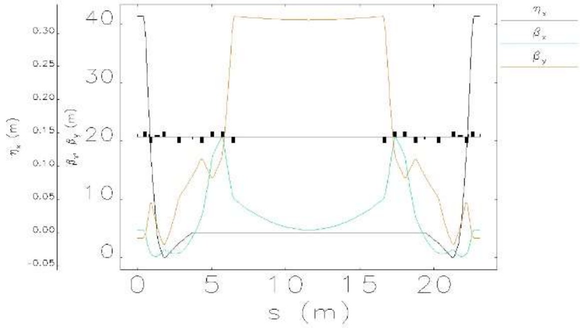

Figure 11: Layout and optical functions of the matching cell.

CONCLUSION

To store micro bunches in a storage ring, not only does the global momentum compaction have to be small, but also the local momentum compaction. When electrons emit photons while travelling through bending magnets, the path length of each electron fluctuates because of the local momentum compaction. As a result, the bunch length is much larger compared to the results of conventional formulas. To suppress this bunch lengthening effect, a lattice consists of isochronous cell is designed. The momentum compaction factor is optimized to be 1e-6 before nonlinear momentum compaction becomes dominant. To further shorten the bunch length, more

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optimization is needed. A longitudinal strong focusing insertion cell will be the next phase of this work.

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