SUPPRESSION OF THE CSR EMITTANCE IN A SINGLE ACHROMATIC CELL

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Abstract

The Emittace growth induced by Coherent Synchrotron Radiation(CSR) is an important issue when electron bunches with short bunch length and high peak current are transported in a bending magnet. In this paper, an optics design technique is introduced which could minimize the emittance dilution within a single achromatic cell. We gave a comparison between this method and the earlier optics method, simulation results confirmed the usefulness of our new result.

INTRODUCTION

The design and study on the next generation light source based on Energy Recovery Linac (ERL) and Free Electron Lasers (FEL) have been proposed worldwide. In these machines, electron bunches with short bunch length, high peak current and small emittance are generated and transported and it is very important to minimize the transverse emittance growth in order to achieve high quality electron beams. Emission of Coherent Synchrotron Radiation (CSR) is considered to be one of the most critical sources for the beam emittance dilution in these cases.

From previous studies[1], it is found that the the CSR induced Energy spread along the bunch length is the main reason for the emittance growth. This effect has been studied intensively[2,3], and it is shown that if the longitudinal electron distribution doesn't change significantly, the rms energy spread caused by CSR can be estimated by the function:

$$\Delta E_{rms} = 0.22\frac{eQL_b}{4\pi\varepsilon_0\rho^{2/3}\sigma_s^{4/3}} \tag{1}$$

Where e is electron charge, Q is the bunch charge, Lb is the length of the bending magnet, ρ is the bending radius and σs denotes the rms bunch length. For constant bending radius, it is a linear function of s, the longitudinal path length, and can βe simplified as △E=ks, where k denotes the coefficient of L_b in function (1) . Under this linear approximation, two optics design techniques have been introduced for the suppression of the CSR induced emittance growth: The envelope matching method[4], and the cell-to-cell phase matching method[5]. In the present paper, another method of emittance cancellation is shown, which can completely cancel the emittance growth due to linear CSR effect within a single achromatic cell.

In his paper [6], R. Hajima proposed a 5-by-5 R-matrix to calculate the emttance growth arising from CSR effect. Using this matrix method, an exact description of the linear CSR effect is acquired and it can be treated as standard transfer matrix. the transverse coordinate movement due to CSR effect can also be treated by a matrix method, a sector dipole can be described by a matrix:

$$R_d = \begin{pmatrix} \cos\theta & \rho\sin\theta & \rho(1-\cos\theta) & \rho(1-\cos\theta) & \rho^2(\theta-\sin\theta) \\ -\sin\theta/\rho & \cos\theta & \sin\theta & \sin\theta & \rho(1-\cos\theta) \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & \rho\theta \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}, \tag{2}$$

Where the R(1,3) and R(2,3) are the dispersion terms, and R(1,5) and R(2,5) are the CSR terms. To cancel keep the achromatic condition and cancel the CSR induced emittance growth, we need these four terms in the matrix to be zero at the same time.

A NEW OPTICS DESIGN METHOD

General lattice will involve complex matrix manipulations, thus in the following sections, we'll keep using a symmetric DBA cell as an example. Shown in Fig. 1.The symmetric DBA cell is composed of two identical sector dipoles and the drifts and quadrupoles between them are also symmetric. The Twiss parameters are chosen to satisfy the condition:β1=β2, α1=−α2, where β1,α1,β2,α2 are Twiss parameters at the middle point of the two dipoles separately, and the phase advance between the middle points of two dipoles is chosen to be π, which is required by the achromatic condition. After many matrix calculations, the CSR cancellation condition in a DBA cell can be get as:

$$\beta_1 = \frac{\alpha 1\rho(-2+\theta\mathrm{Cot}\frac{\theta}{2})}{\theta} \tag{3}$$

for θ<<1, a condition most transport dipoles fulfill, this condition can be simplified as:

$$\beta_1 \sim \alpha 1\rho\theta/6 \tag{4}$$

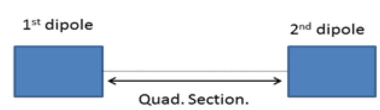

Figure 1: Layout of a double-bending cell.

PARTICLE NUMERICAL SIMULATIONS

This method of emittance compensation is confirmed by a simulation using the particle tracking code ELEGANT. The initial condition of the electron bunch is assumed to be: central energy 1GeV, bunch charge Q=500 pC, normalized emittance εn=0.2 mm.mrad, bunch length σs=100fs. For our purpose, symmetric DBA cells with different initial Twiss parameters are constructed and simulated using ELEGANT, the bending angle of dipoles are 3 degree. From our emittance cancellation condition

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(4), we can find the requirement on the Twiss parameters at the entrance of the DBA cell:

$$2\beta_0^2\rho\cot(\theta/2)-2\beta_0\alpha_0[\rho^2-\cot^2(\theta/2)]-2\rho\cot(\theta/2)(1+\alpha_0^2)=0. \quad (5)$$

Where $\beta 0$, $\alpha 0$ are the Twiss parameters at the DBA entrance, and θ , ρ are bending angle and radius of the dipoles. Simulation results are shown in Fig. 2. A comparison between our new method and the cell-to-cell method is also done, and the results are given in Fig. 3. From these simulations, we found that our new method can give better results than these previous methods.

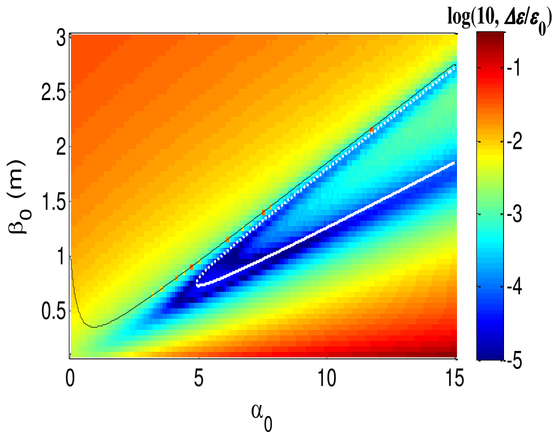

Figure 2: Simulation results of DBA lattices with different $\alpha 0$, and $\beta 0$. The white line represents DBA lattices that meet our condition (4), and the black line represents lattices satisfy the envelope matching condition.

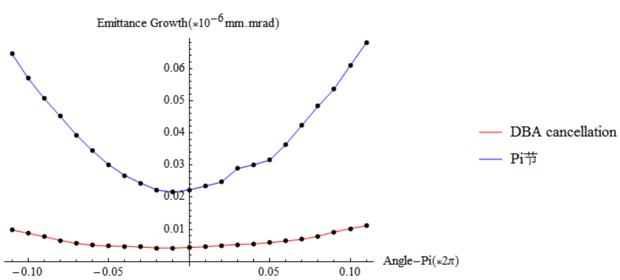

Figure 3: A comparison between the new optics method and the cell-to-cell matching method.

CONCLUSION

In conclusion, we have derived an optics design technique which can significantly suppress the emittance growth induced by CSR within a single achromatic cell, and this has been verified by simulation results. We believe that using similar derivations shown above, this technique can be expanded to be used in the design of other types of achromatic cells such as asymmetric double bending cells or TBAs, etc. However, in our study above we have assumed a constant bunch length and linear approximation of the CSR induced energy spread, so that in beam transport systems where the bunch length changes significantly, or nonlinear effects of CSR takes an important role, further studies are still needed.

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