BUNCH COMPRESSOR DESIGN FOR POTENTIAL FEL OPERATION AT ERHIC*

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Abstract

Electron-Relativistic Heavy Ion Collider (eRHIC) is an upgrade project for RHIC. A 30 GeV energy recovery linac (ERL) will provide a high quality electron beam to collide with proton and ion beams. It is natural to think about taking advantage of using this electron beam for FEL operation [1]. Since the beam current in ERL arcs has to stay low, a strong bunch compressor is a crucial component for such FEL scheme. In such compressors, the CSR effect plays very important role and can adversely affect the beam quality. In this paper, we present our novel bunch compressor design with CSR suppression scheme. We also study its potential for FEL operation at eRHIC.

INTRODUCTION

A multi-GeV electron beam with high peak current and low natural emittance is required for a high-performance X-ray FEL [2, 3, 4]. The future eRHIC ERL can be an excellent platform of providing such high quality electron beam. For exercise in this paper we chose the e- beam energy of 10 GeV allowing to reach hard X-ray range with current undulator technology. Such hard X-ray FEL requires a peak current of a few kA to reach saturation in single pass.

LAYOUT OF THE BUNCH COMPRESSING SYSTEM

Current layout of eRHIC is shown in Fig. 1. For the FEL operation, the bunch compressor system will be located in a bypass at 12 o'clock. The electron beam will be further guided into the bypass on its second pass in eRHIC where the beam energy is about 7.55 GeV. The cavity located at 2 o'clock will be detuned from on crest operation to induce a correlated energy spread for bunch compression. The energy spread has to be kept to a small value (less than 2×10^{-4} RMS). Thus the strong compression ratio requires a large value of R56. This requires a high-field compressor with a very strong coherent synchrotron radiation (CSR) effect, which would deteriorate beam quality in a standard chicane.

We use beam parameters listed in Table 1 and parameters for rf systems listed in Table 2.

Single C-type Chicane

As expected the CSR in a compressor based on a common C-type chicane strongly affect the beam. As mentioned before, strong dipoles provide strong CSR wakefields which blow up the beam emittance 4 to 5 - fold. Results of our simulation of emittance growth in this system are shown in Fig. 2. The growth comes from the fact that the CSR wake depends both on longitudinal position within the bunch and on the azimuth (because of the field in the chicane and the bunch compression). The head gains energy due to the CSR wakes and the tail part loses energy [5].

The corresponding energy variation induce coordinate

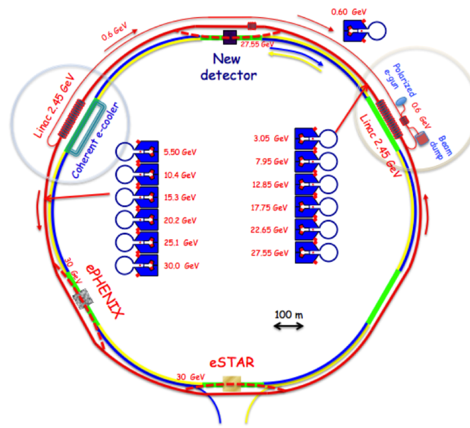

Figure 1: eRHIC layout with a 6 pass 30 GeV ERL. For FEL operation, the bunch compressor will be located at 12 o'clock, while two main linacs are at 2 and 10 o'clock respectively.

Table 1: Beam Parameters for e- Beam in FEL Operation Mode of eRHIC after First Pass

Name	Value
Energy (GeV)	5.5
Bunch charge (nC)	0.2
Rms bunch length (mm)	0.3
Rms energy spread (1e-6)	4.5
Rms normalized emittance (μm)	0.2

Table 2: RF System Parameters for Bunch Compression Simulations

Name	Value
$E_{rf,2}$ (MV/m)	12.5
$\phi_{i,2}$ (deg)	77.8
$E_{rf,10}$ (MV/m)	12.5
$\phi_{i,10}$ (deg)	90.5

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and angular displacements of the particles in the transverse plane via R_{16} and R_{26} induced in the chicane. This effect can be visualized by transverse phase space plots before and after chicane (Fig. 3 and Fig. 4). Our cure for this is to implement a proper combination of two chicanes to compensate the CSR effect.

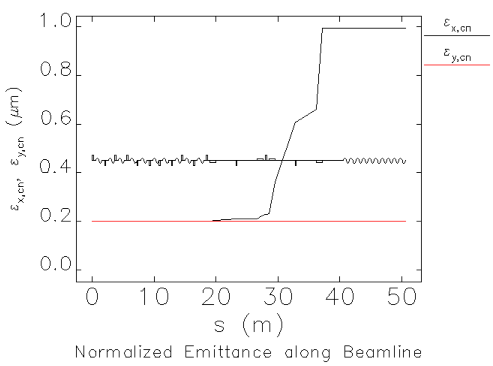

Figure 2: The e-beam emittance evolution in the bunch compressor using a single chicane. The emittance blown-up is caused by the CSR effect.

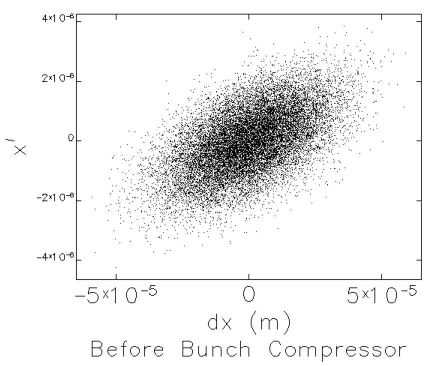

Figure 3: Phase space distribution before bunch compressor.

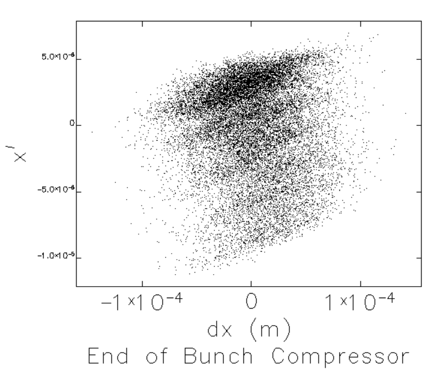

Figure 4: Phase space distribution after bunch compressor.

Compressor with Two Chicanes

We propose using two chicanes with reversed bending directions (e.g with opposite signs of the dispersion functions) to de-couple the longitudinal and transverse degrees of freedom. In the simulations, we use initial electron beam with Gaussian distribution and track 200,000 particles along the whole system using the code ELEGANT. CSR effects and incoherent synchrotron radiation (ISR) are included in the process as well as random higher order field errors are also included in dipoles and quadruples. We analyze and post process the data using MATLAB.

A sketch of the energy variation along the bunch trajectory is shown in Fig. 5.

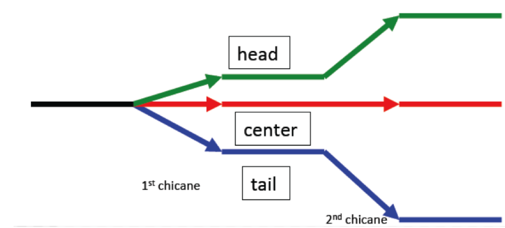

Figure 5: A sketch of expected energy variation along the two-chicane compressor. Because of the higher peak current, the CSR wakes in second chicane is stronger and a larger energy change is expected.

Because bunch length is shorter in second chicane, the CSR wakes are stronger and energy change becomes larger. Thus the cancellation of the CSR effect requires the second chicane to be weaker then the first one. Also, adjusting phase advance between two chicanes could allow aligning various slices of the bunch and to minimize the overall projected emittance.

Figure. 6 shows resulting emittance as a function of the betatron phase advance between two chicanes for a number of relative strength ratios between the two chicanes. While we changed the ratio of R_{56} in two chicanes, the total R_{56} of the compressor remained constant. The optimal compression ratio between two chicanes turned out to be 4 to 1, i.e. the second chicane has four times lower R_{56} compared with that of the first chicane. Tuning the phase advance reduced the CSR-induced emittance growth to 65%, compared with 5-fold increase in a single chicane.

Furthermore, by tuning the optics functions (β-function, α-function, as shown in Fig. 7 and Fig. 8), we can reduce the overall emittance growth to about 30%, e.g. at least one order of magnitude below that in the single-chicane bunch compressor. Thus, using two chicanes with opposite bending directions (zigzag style [6]) and a proper betatron phase advance between them, we can minimize the CSR effect on the e-beam quality.

FEL PERFORMANCE WITH THE CSR-MATCHED COMPRESSOR

We used the particle distribution after the chicane as input into GENESIS and simulated the FEL performance at

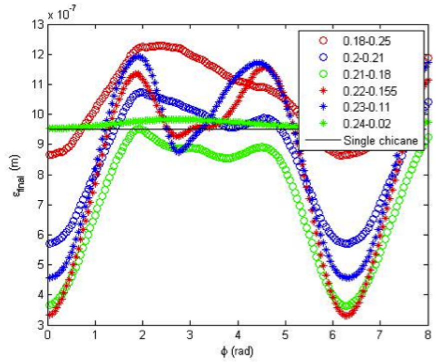

Figure 6: Horizontal axis is the phase advance between two chicanes, while vertical axis is the horizontal emittance after the bunch compressor. The single chicane scheme with a growth factor of 5 is also shown as baseline.

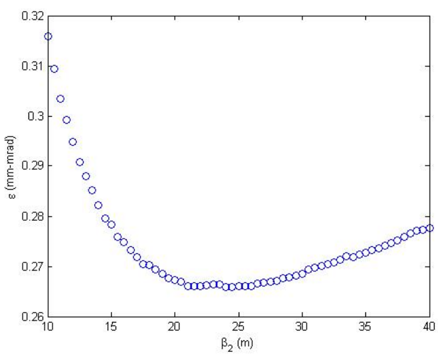

Figure 7: The β-function scan shows an optimum around $\beta = 22.5m$.

X-ray wavelength of 1 (see Fig. 10). The simulations showed an excellent performance with fitted 3D gain length to be 3.1 m and saturation reachable at 140 m. We are looking for ways of further optimizing the FEL system

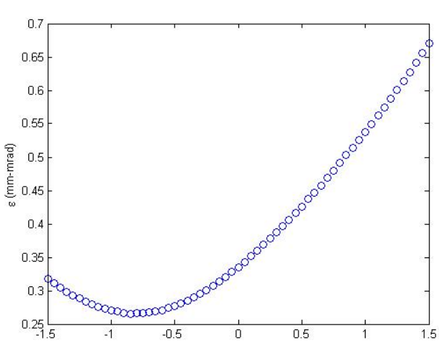

Figure 8: The α-function scan shows an optimum around $\alpha = -0.85$.

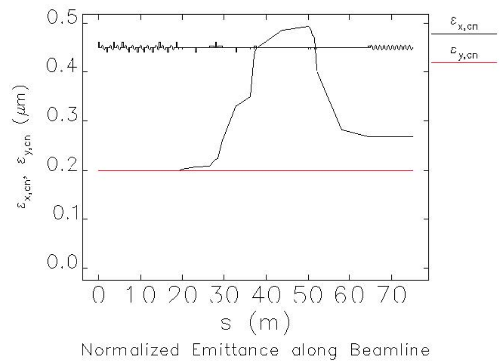

Figure 9: The emittance growth in first chicane is largely compensated in second chicane with careful tuning of all parameters.

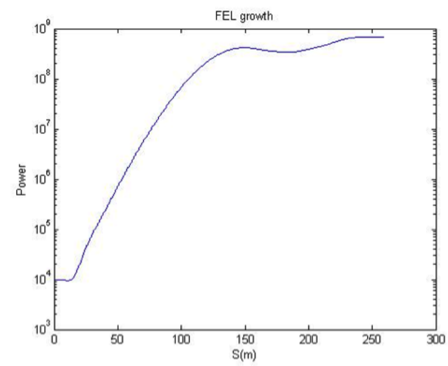

Figure 10: Power growth and saturation in 1 X-ray FEL predicted by GENESIS.

CONCLUSION.

We proposed a novel bunch compressor comprised of Zigzag type chicanes to greatly reduce CSR-induced emittance growth. By tuning the relative chicane strengths, the phase advance between two chicanes and optimizing the optics functions, we showed that CSR-induced emittance growth can be reduced to about 30%. Resulting beam is well suited for driving high-performance hard X-ray FELs.

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