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DESIGN OF BUNCH COMPRESSING SYSTEM WITH SUPPRESSION OF COHERENT SYNCHROTRON RADIATION FOR ATF UPGRADE

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Abstract

One of the operation modes for Accelerator Test Facility (ATF) upgrade is to provide high peak current, high quality electron beam for users. Such operation requires a bunch compressing system with a very large compression ratio. The CSR originating from the strong compressors generally could greatly degrade the quality of the electron beam. In this paper, we present our design for the entire bunch compressing system that will limit the effect of CSR on the e-beam's quality. We discuss and detail the performance from the start to end simulation of such a compressor for ATF.

INTRODUCTION

Accelerator Test Facility (ATF) is ungoing an upgrade to provide users with wider spectrum of possiblities and choices. One of the most interesting applications is biology and material science which requires high charge and peak current. Such applications would make ATF become prime source for cutting edge research in photon sciences [1]. This requires a relatively higher energy (semi-GeV) electron beam with high peak current (kA) and low emittance.

The beam lines, which resembles High-gain Free electron lasers (FELs), usually are comprised of a low peak current electron beam generated at sources for acceleration and a strong bunch compressor to compress such a low peak current to a kA-level peak current for the users and other beamlines. In linac based SASE FELs, this compression usually is distributed in multiple stages along the beam transport at different energies of the beam. The linacs between two stages, in addition, could be used to accelerate the electron beam to higher energy and to prepare the electron beam for the next stages of compression. In such a way, each buncher's compression factor could be reduced (e.g. via a partial rotation in longitudinal phase space) so resulting in an overall lowering of emittance growth. Further more, the phase and strengths between different stages could be tuned for optimal performance. However, if a single stage compression can be achieved (without sacrifice of beam qualities), it benefits the layout of ATF and its upgrade. Further more, many different beam lines (for different users) can be installed downstream to such compressor to share the high quality electron beam. However, one concern of a single bunch compression scheme is CSR which could greatly degrade the quality of the e-beam [2–4].

In this paper, we present our design for a bunch compressor that will limit the effect of CSR on the e-beam's quality. We further perform the start-to-end (S2E) simulation to show our findings from a study of such a compressing scheme.

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C-SHAPE CHICANE VS ZIGZAG CHICANE

A traditional approach to e-beam compression is to use a C-shape compensated chicane comprised of four dipole magnets. In such a chicane, the paths' lengths, as well as the transit time through the chicane, depend on the particles' energy. In combination with the correlated energy spread (chirp), this entails a rotation in longitudinal phase space. The emittance growth originates mostly from the third and forth magnets, where the beam is already compressed and the peak current is high. This growth in transverse emittance reflects the fact that the CSR wake depends both on longitudinal position within the bunch, as well as on the azimuth along the beamline. The head of the bunch gains energy while the tail part loses energy [5]. Furthermore, the location-dependent energy variation $\delta E(z, s)$ induced by CSR wakes engender transverse coordinate- and angular- displacements via non-zero $R_{16}(s, s_2)$ and $R_{26}(s, s_2)$ induced in the chicane. At the end of the chicane, the transverse displacement and the angle deviation will be non-zero.

The coordinate and the angular displacement that depend on longitudinal position of the particle result in a smearing in the transverse phase space, and also in the growth of the projected emittance. Figure 1 illustrates this smearing effect, comparing the plots of the transverse phase space before and after the chicane, which indicites a typical few fold of emittance growth for a C-shape chicane.

As a remedy for the above problem, i.e., the displacement in the transverse plane due to the longitudinal energy variation induced by CSR wakes, we propose to use two consequent chicanes with reversed bending directions, i.e., a Zig-Zag type compressor [6] as is shown in Fig. 2. The opposite signs of the dispersion functions should allow us to decouple the longitudinal and transverse degrees of freedom. We expect that in our scheme the transverse phase space displacement caused by CSR in the 1st chicane could be, at least, partially reversed in 2nd chicane. Thus, the resulting emittance growth due to CSR effects could be greatly reduced. Since bunch length is shorter, correspondingly CSR wake is stronger in the second chicane, and the energy change also is larger. The cancellation of the CSR effect naturally requires a weaker second chicane compared to the first one. In addition, we could better align the transverse phase-space displacements originating from two chicanes by adjusting phase advance between them.

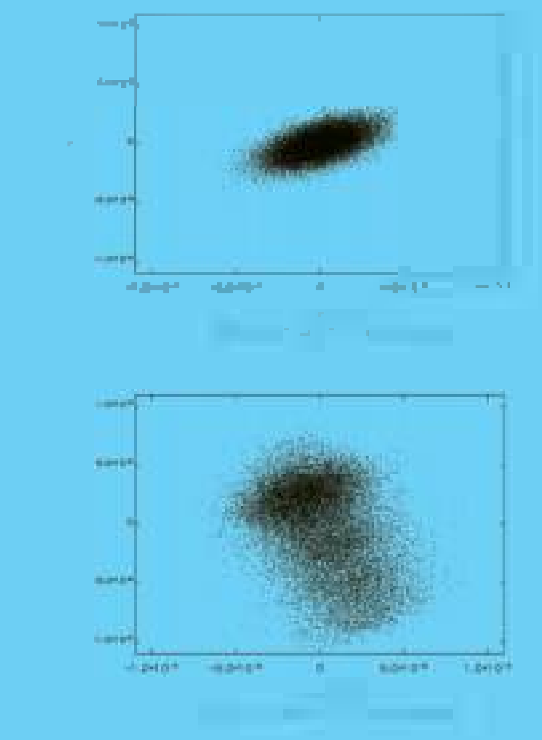

Figure 1: Phase space distribution before (left) and after (right) the bunch compressor. The longitudinal energy variation induced by CSR wakes is coupled to the coordinate and angular displacements through R_{16} and R_{26} induced in the chicane. This results in smearing of the transverse phase space.

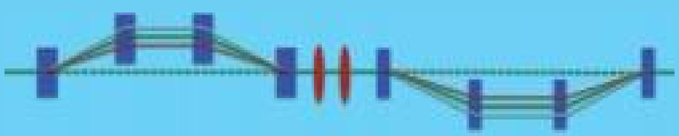

Figure 2: A schematic drawing of a zigzag chicane with optics matching sections.

S2E SIMULATION AND BEAM DYNAMICS FOR THE ATF UPGRADE PHOTO-INJECTOR

To prove the feasibility of such compressing system on ATF, we perform a S2E simulation using the codes ASTRA and ELEGANT. The electron beam is generated and propagated through the low-energy beamline as is illustrated in Fig. 3. The electron source includes a 2.856 GHz 1.6 cell rf gun with a photocathode located on the back which is illuminated by a uv drive laser. The charge can range from a few pC up to 3 nC. For a peak electric field of 110 MV/m the beam's mean energy is approximately 5 MeV downstream of the gun. The gun is surrounded by a solenoid magnet which is used to correct for the space-charge induced correlated emittance growth.

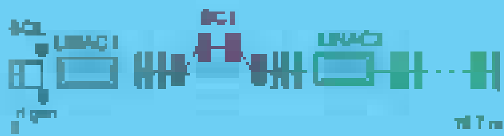

Figure 3: Overview of the ATF upgrade photo-injector. SOL is the solenoidal lens, LINAC 1, LINAC2 are the 2.856 GHz SLAC sections. BC1 is the bunch compressor chicane.

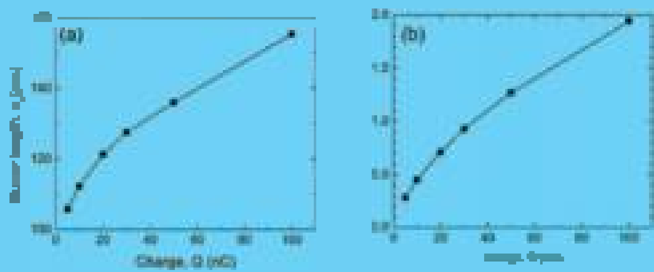

Figure 4: Bunch length as a function of charge and corresponding normalized transverse rms emittance.

After the rf gun, two three meter long traveling wave structures, also known as "SLAC sections" (LINAC 1 and LINAC 2), are used to elevate the beam energy to 140 MeV approximately. The downstream beamline includes several quadrupole focusing triples and a four bend chicane bunch compressor (BC1). The compressor has a 12.2 deg. bend angle. For purpose of this study the chicane will be turned off.

Multi-particle simulations were used to evaluate the photo-injector beam dynamics. First, the injector (up to BC1) was modelled using ASTRA with 100k macroparticles. Then, these macroparticles were used as input in ELEGANT and tracked through the remaining lattice. Note that the code includes a 1-D model of coherent synchrotron radiation and will be used to evaluate the downstream results.

The performance of the injector was explored for a variety of charges ranging from 5 pC to 100 pC. The initial distribution assumed in the simulations is matched to the type of distribution expected from a properly shaped laser beam. That is we assume a Gaussian distribution in z and a uniform radial distribution in the transverse directions (x and y). Figure. 4 displays the transverse emittance and corresponding bunch length for six considered charges. All results are collected downstream of LINAC2 at z=16.7 m from the photo-cathode.

Figure. 5 displays the ELEGANT simulated current profile and longitudinal phase-space for the 5 pC (top row) case and 50 pC case (bottom row). It is clear that the beam develops an energy-time correlation which is near linear for the low charge beam which is the results of space charge effect.

We tracked the particle 6D distribution in ELEGANT and optimized the beam line setups (in 10D parametric space using a self-developed external object oriented code). We implemented G. Stupakov's model [8,9] to simulate coherent

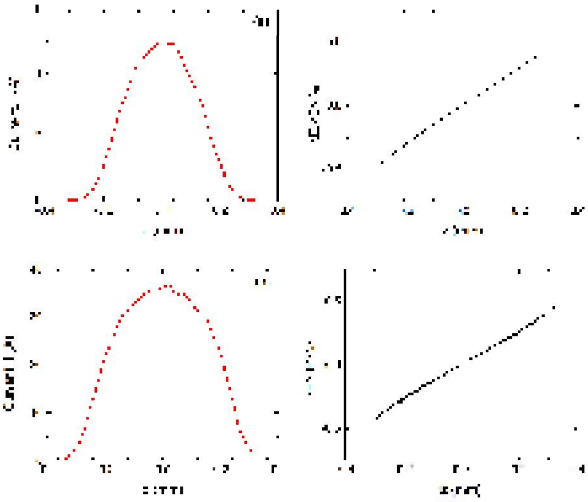

Figure 5: Current profile (left row) and longitudinal phase-space for Q=5 pC (top row) and Q=50 pC (bottom row). For the profiles the beam was divided in several longitudinal slices.

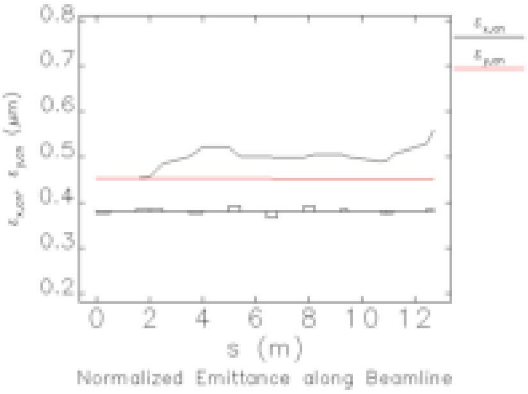

Figure 6: The emittance growth in the chicane is largely compensated with careful tuning of all parameters.

synchrotron radiation in dipoles and near-by drift spaces. A recurrent process of optimizing the compensation scheme is done in scanning the dipoles' angles, the distances between dipoles, the phase advance between two chicanes and the beam optics at the entrance of both chicanes. We show the emittance evolution in the beam line in Fig. 6 and final charge histogram at the end of chicane in FIg. 7. The chicane setup is listed in Table. 1.

Table 1: Parameters of the zigzag type bunch compressor

Name	1st chicane	2nd chicane
Dipole angle (rad)	0.133	0.089
Dipole length (m)	0.5	0.25
Drift dipole 2 and 3 (m)	0.1	0.1
Drift dipole 1 and 2 (m)	1	1.25

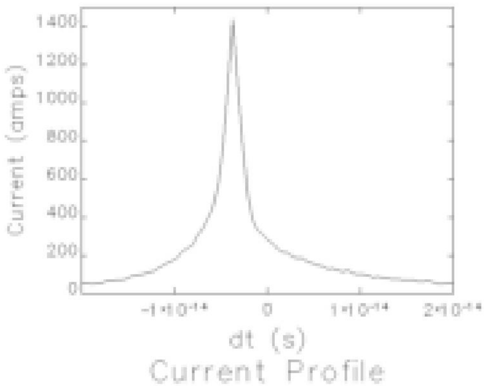

Figure 7: The current distribution along the bunch at the end of Zig-zag bunch compressor.

By utilising this CSR compensated chicane, we successfully achieved an electron beam with peak current exceeds 1.4 kA with very good emittance preservation through the beam line. Such scheme will be implemented in the future ATF upgrade.

CONCLUSIONS.

We describe our design of a bunch compressor comprised of Zig-Zag type chicanes to suppress CSR-induced emittance growth. By carefully tuning the relative strengths of the chicanes, the betatron phase advance between them and by optimizing the optics functions, we demonstrate that we could reduce CSR-induced emittance growth, while achieving very high peak current. Our start-to-end simulation verified that the resulting beam is well suited for driving high-performance ATF operations.

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