BUNCH COMPRESSOR AND DE-COMPRESSOR IN THE FEL FOR SATELLITE POWER BEAMING*

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Abstract

A FEL of average power 200 kW is being designed at the LBNL for satellite power beaming[1, 2]. It utilizes the radiation of ∼100 MeV electrons with ∼200 A peak current. In order to obtain the desired peak current, the 5mm long electron bunches delivered by a linear accelerator are compressed to 1mm. Furthermore, it is important for the FEL operations that the compressed bunches have a uniform longitudinal density distribution over the entire bunch length. After the FEL, the electron beam is returned to the linear accelerator for deceleration. Since the electron beam acquires approximately 6% energy spread during radiation in the FEL, bunch de-compressor is used between the FEL and the linac to expand the electron bunches back to its original length and to reduce the energy spread. In this paper we present design and analysis of the bunch compressor and the bunch de-compressor that perform needed functions.

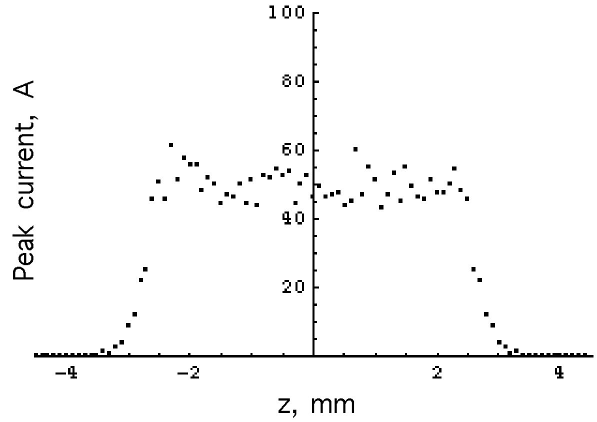

Figure 1: The longitudinal distribution of electron peak current at the end of the RF photoinjector. Point to point fluctuations on the plot are due to limited statistics in the simulation.

1 INTRODUCTION

This work is part of a broader study aiming at the design of a FEL for satellite power beaming [1]. At present a FEL of average power 200 kW at the wavelength of 840 nm is being designed at the LBNL [2, 3]. The FEL utilizes a ∼100 MeV electron beam with the average beam power of ∼10 MW provided by a RF photoinjector and a linear accelerator. The design assumes a low beam peak current in the injector and the linear accelerator and a high beam peak current in the FEL. A compression of electron bunches is needed between the linear accelerator and the FEL. The goal of the compression is not only a short bunch in the FEL, but also a bunch that has a uniform longitudinal electron density profile over most of the bunch length. The former helps to improve the efficiency of the energy transfer from electrons to light; the latter helps to minimize the energy spread of electrons after the radiation. This is important because the FEL design assumes that the electrons are decelerated in the linear accelerator to below 12 MeV before they are sent to the dump, which is employed for energy recuperation in the linac and the elimination of induced radioactivity in the dump. Therefore, too large energy spread of the electrons will hamper the deceleration process.

In the process of the radiation in the FEL the electrons lose about 2% of their energy and acquire roughly an energy spread of 6%. Bunch de-compressor uses this energy spread to disperse the compressed electron bunch back to its original length. It also creates a correlation between energy of electrons and their position along the bunch, which is used to reduce energy spread of electrons at the end of the deceleration.

2 BUNCH COMPRESSOR AND DE-COMPRESSOR

The design requirement for a bunch compressor is a reduction of the electron bunch length from approximately 5 mm at the end of the linear accelerator to 1 mm at the beginning of the FEL. This will raise the electron peak current in the FEL up to more than 200 A.

At this point we assume that an electron bunch leaving the RF photoinjector has a normalized longitudinal emittance of 6 cm and a uniform longitudinal distribution, as shown in Fig. 1 (This distribution is considered in a design of the RF photocathode gun). We begin bunch compression by creating energy shift of the electrons correlated with the electron position along the bunch. This is accomplished by accelerating the electron bunches in the linac at a -13° phase off the peak accelerating field. Ideally, we want to produce a linear dependence of the electron energy shifts on the longitudinal coordinates of the electrons relative to the bunch center. But, it is impossible because the acceleration takes place in a sinusoidal RF field and, together with the linear term, it inevitably produces nonlinear terms. However, one can use the actual dependency of the electron energy shift on the longitudinal coordinates and derive a required path-length difference as a function of electron energy. Usually, the first three terms are sufficient for an accurate descrip-

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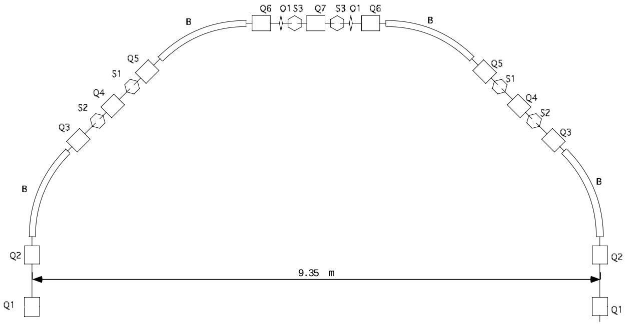

Figure 2: The layout of the bunch compressor

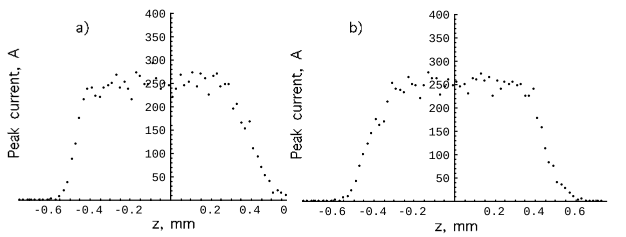

Figure 3: The longitudinal distribution of electron peak current after bunch compression: a) without errors, b) with errors. Point to point fluctuations on the plot are due to limited statistics in simulations.

tion. In our case they turn out to be:

$$\delta L = -0.514\frac{\Delta E}{E} - 3.88\left(\frac{\Delta E}{E}\right)^2 - 177\left(\frac{\Delta E}{E}\right)^3 \quad (1)$$

where all coefficients on the right hand side of the equation have a dimension expressed in meters. Now, this function can be programmed into the performance of the bunch compressor to produce the uniform longitudinal distribution at the exit. This is to force all electrons to radiate in the identical conditions in the FEL and, therefore, to minimize the energy spread produced in the process of the radiation.

In this design we incorporated the bunch compressor into a magnetic arc performing a 180° beam turn from the end of the linear accelerator to the FEL. Its layout is shown in Fig. 2. The arc's lattice consists from two identical cells and resembles a second-order achromat. Each cell has 2 bending magnets, 8 quadrupoles and 4 sextupoles. The strengths of all quadrupoles and sextupoles are chosen to provide a smooth beam focusing in the arc and time-of-flight lattice terms defined by Eq. 1. Care was given to the choice of linear optics to minimize the strengths of the sextupoles. As a result, the magnetic field of the sextupoles at the pole tip is well below 1 kG (assuming 5 cm radius of the beam pipe).

To test the lattice we did particle ray tracing using COSY INFINITY [4]. We assumed 8 mm-mrad for normalized vertical and horizontal beam emittance. The result of simulation without lattice errors is shown in Figure 3. Here one can see the longitudinal distribution of the electron peak current after bunch compression. One can see that the final distribution has a flat top extended almost over the entire

	Static errors
Setting errors	$\sigma(\frac{\Delta B}{B}) = 1 \times 10^{-3}$ $^{a)}$
Tilt errors (mrad)	$\sigma(\Delta\psi) = 0.2$
Misalignment errors	
in x, (μm)	$\sigma(\Delta x) = 150$
in y, (μm)	$\sigma(\Delta y) = 30$
in z, (mm)	$\sigma(\Delta z) = 1$
Multipole errors	
dipoles	$\sigma(\frac{b_3}{b_1}) = 1 \times 10^{-4}$ at $r = 3$cm $^{b)}$
quadrupoles	$\sigma(\frac{b_3}{b_2}) = 5 \times 10^{-4}$ at $r = 5$cm $^{b)}$

$^{a)}$ b_1, b_2 and b_3 are the dipole, quadrupole and sextupole components of the magnetic field

$^{b)}$ the same for quadrupoles and sextupoles

Table 1: Specification of the errors

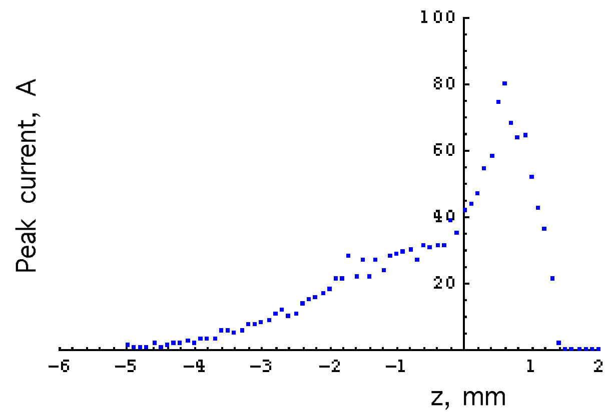

Figure 4: The longitudinal distribution of electron peak current after bunch compression with no errors and sextupoles and octupoles turned off.

bunch length even with all errors being included in simulation. Then we applied all kinds of lattice errors like misalignment errors, tilt errors, setting errors listed in Table 1 and use two families of quadrupoles to offset the linear perturbations to the lattice due to the setting errors. We assume that similar knobs will be used with an actual beam for an initial tuning of the lattice. Then we did particle ray tracing again. A typical result of a simulation for one seed of errors is shown in Fig. 3. Obviously, errors have little effect on the performance of the bunch compressor. To demonstrate the importance of the sextupole corrections we show the result of similar particle ray tracing for a case when all sextupoles are set to zero in Fig. 4. It is clear in this case that sextupoles play a crucial role in producing the desired beam profile. In fact, with sextupoles off, the term T_{566}, following the TRANSPORT notation, is about 135 m, responsible for 3.4 mm bunch lengthening of a beam with energy spread of $\pm 0.5\%$. Since the present solution with sextupoles turned on works well for our purpose, no extra effort was devoted to optimize the first-order layout to further minimize the second-order aberrations.

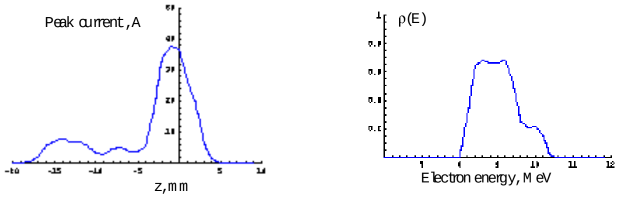

Figure 5: The longitudinal distribution of electron peak current and energy distribution of the spent beam at the end of the linac.

2.1 BUNCH DE-COMPRESSOR

The function of the bunch de-compressor is the reverse of the bunch compressor. It takes the compressed electron bunch with large energy spread acquired in the FEL and uses this energy spread to disperse electrons. For this purpose we use the second 180° arc to return electrons to the linear accelerator. Physically this arc is similar to the first arc, but quadrupoles and sextupoles are set to different strengths. The de-compressor creates the correlation desired between electron position in the bunch and its energy. This correlation is used in the linac for a partial compensation of the beam energy spread. This is accomplished by decelerating the electron bunches in the linac at a 13° phase off the peak accelerating field. A result of the de-compression of the electron bunch and deceleration in the linac is shown in Fig. 5. Here we present a distribution of the electron peak current and a distribution of the electron energy in the bunch of spent electrons at the end of the linac.

One can see that at the end of the deceleration the total energy spread of the electrons is roughly 2.5 MeV, while at the beginning of the deceleration it is about 5 MeV as shown in Figure 5.

3 CONCLUSION

The study presented in this report shows that the carefully designed bunch compressor and de-compressor meet the requirement of the FEL for power beaming and thus enhance its efficiency.

4 REFERENCES

[1] H. E. Bennett, et. al., NIM A341, (1994)124-131.

[2] K.-J. Kim, et. al., "FEL Options for Power Beaming", NIM A407, (1998)380.

[3] A. Zholents, et al., "FEL Design for Power Beaming", to be published in SPIE Proc. 3614.

[4] M. Berz, Technical Report MSUCL-977, Michigan State University, (1995).