A HIGHLY FLEXIBLE BUNCH COMPRESSOR FOR THE APS LEUTL FEL *

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Abstract

The Low-Energy Undulator Test Line (LEUTL) free-electron laser (FEL) [1] at the Advanced Photon Source (APS) has achieved gain at 530 nm with an electron beam current of about 100 A [2, 3]. In order to push to 120 nm and beyond, we have designed and are commissioning a bunch compressor using a four-dipole chicane at 100-210 MeV to increase the current to 600 A or more. To provide options for control of emittance growth due to coherent synchrotron radiation (CSR), the chicane has variable R_{56}. The symmetry of the chicane is also variable via longitudinal motion of the final dipole, which is predicted to have an effect on emittance growth [4]. Following the chicane, a three-screen emittance measurement system should permit resolution of the difference in emittance growth between various chicane configurations. A vertical bending magnet analysis line will permit imaging of correlations between transverse and energy coordinates [5]. A companion paper discusses the physics design in detail [4].

1 APS LINAC OVERVIEW

The APS injector consists of a linac, an accumulator ring, and a 7-GeV booster synchrotron. In addition to delivering beam to the accumulator, the linac can be configured [6] to deliver beam to the LEUTL experiment hall [1]. The linac consists of 13 Stanford Linear Accelerator Center (SLAC) type accelerating sections powered by four klystrons, two thermionic rf guns (TRFG) [7, 8, 9] powered (one at a time) by a single klystron, and one photocathode gun (PCG) [10] powered by a single klystron. Figure 1 shows a schematic of the system and the location of the newly-installed bunch compressor.

The original purpose of the linac was to create positron beams and deliver them to the accumulator ring for injection into the APS. The positron target was subsequently removed when the APS switched to electron operation. In both situations, the requirements on the linac were modest in terms of emittance, energy spread, bunch length, and stability. However, the requirements for reliability were and are very high, which was one reason for elimination of positron operation. The FEL project requires much higher beam quality and beam stability. The required beam quality is typically only achieved using a photocathode gun; however, the reliability of such guns (particularly the drive laser) is insufficient to act as an injector for the APS. The dual thermionic guns have a distinct advantage here, having proven themselves as components of the injector at SSRL [11]. The use of alpha magnets [7] for magnetic bunch compression in these guns allows the guns to be placed off-axis, leaving the on-axis position for the PCG. This is an important consideration in preserving the PCG beam brightness.

2 MAGNETIC BUNCH COMPRESSION

The principle of magnetic bunch compression is well-known, so we only review the basic idea here. In a magnetic chicane (see Figure 1) the path length traveled by a particle is $s = s_o + R_{56}\delta$, where s_o is the central path length and $\delta = (p - p_o)/p_o$ is the fractional momentum deviation. For simple chicanes, $R_{56} < 0$ so that high-energy particles take a shorter path.

Phasing the beam ahead of the crest in the precompressor linac introduces an "energy chirp" into the beam, so that the tail of the beam has higher energy than the head. As a result, the tail will catch up to the head in the chicane, giving a shorter bunch. If the beam is undercompressed, then the energy spread imparted in the precompressor linac can be removed by phasing behind the crest in the postcompressor linac.

It is possible to derive formulae for the phasing required to obtain a desired bunch length and minimized energy spread. However, accurate calculation requires including wakefield effects and depends on the detailed initial bunch shape. Hence, we used simulation to find the optimal values [4].

3 LEUTL BEAM REQUIREMENTS

The primary goal of the bunch compressor is to provide higher current beam to the LEUTL FEL. A secondary goal is characterization of CSR effects. The bunch compressor was designed with two LEUTL operating points in mind. These operating points, distinguished primarily by the beam current of 300 or 600 A, are summarized in Table 1. The requirements for charge and emittance are not difficult compared to the state-of-the-art for photoinjector systems. We hope that these parameters can be achieved repeatably and easily to provide for routine and stable operation.

Because of the very non-Gaussian longitudinal phase-space distributions one typically sees in the compressor, we use the following definition for the beam current: $I_{80} = \frac{0.8*Q_{total}}{\Delta t_{80}}$ where Q_{total} is the total charge in the beam and Δt_{80} is the length in time of the central 80% of the beam. The value of 80% was used because this includes most of the particles but typically excludes high-current spikes that tend to occur at the head and tail. Also, when we refer to

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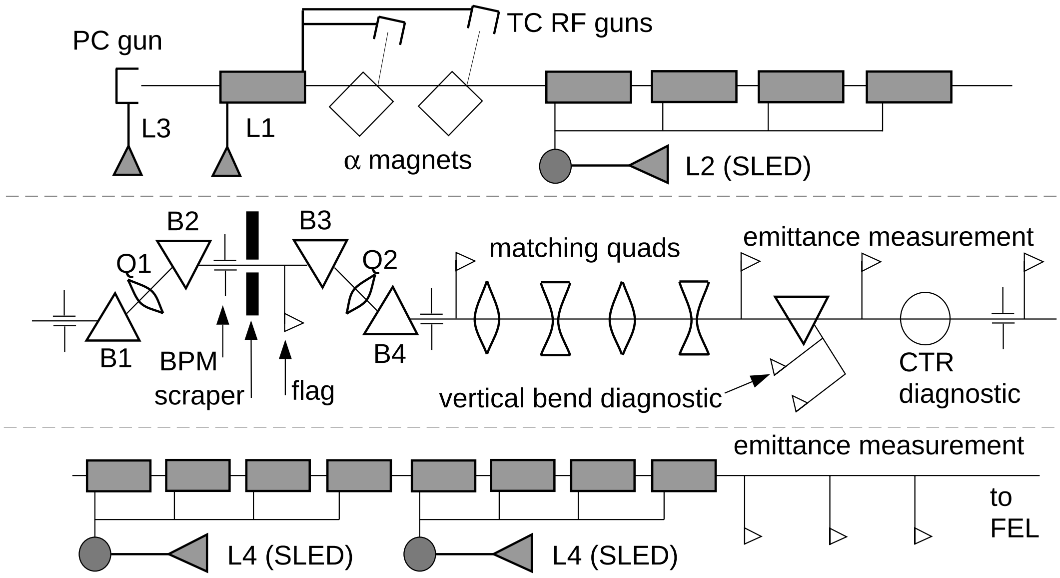

Figure 1: Schematic of the APS linac with the bunch compressor.

bunch length, we mean Δt_{80}.

Because the initial emittance is relatively large, it is desirable that compression not make it larger. For the 600-A case, however, simulations [4] predict an emittance growth of up to 40% due to CSR. Hence, this part of the LEUTL requirement may not be met.

Table 1: Desired LEUTL Operating Points

	Nominal	300 A	600 A
Current (A)	100	300	600
Energy (MeV)	217	217	457
RMS en. spread (%)	<0.1	<0.1	<0.15
Initial charge (nC)	0.5	0.5	0.5
Final charge (nC)	0.5	0.42	0.42
Δt_{80} (ps)	4	1.1	0.55
Norm. emittance (μm)	5	5	5
Light wavelength (nm)	530	530	120

4 BUNCH COMPRESSOR FEATURES

Figure 1 provides a detailed schematic of the compressor chicane. One sees that most of the beam energy at the entrance to the bunch compressor is due to the “L2” sector of the linac, which consists of a single SLEDed klystron driving four SLAC-type 3-m structures, delivering a beam energy of up to 210 MeV. The bunch compressor was designed with the range from 100-210 MeV in mind.

Table 2 shows some of the principle parameters of the bunch compressor. A noteworthy feature of the APS design is that the R_{56} is designed to be variable, which will be accommodated through transverse motion of the central dipole pair (B2 and B3 in Figure 1). This permits variation of the bending angle without having to design magnets with large good field regions. As a result, we can vary R_{56} between 0 and -65 mm. Presently, due to delivery problems with the flexible chambers, the chicane is installed with fixed chambers. Later this year we will install flexible curved chambers in all the dipoles and telescoping chambers between the dipoles. The hardware required for motion of the magnets is already in place.

Table 2: Bunch Compressor Parameters

Maximum bend angle	13.5°
Maximum bend field	0.86 T
Effective bend length	192 mm
Maximum R_{56}	-65 mm
Maximum transverse motion	184 mm
Maximum longitudinal motion	602 mm

The symmetry of the chicane will also be variable through longitudinal motion of the final dipole, B4. The ratio of the B3-B4 distance to the B1-B2 distance will be variable from 1.0 to 2.0, corresponding to variations in the ratio of the angle of B1 to the angle of B4 from 1 to 1.8. Two “tweaker” quads are required within the chicane to allow matching the dispersion for asymmetric configurations.

Variable R_{56} and symmetry is thought to be interesting in that the effect of CSR should change with these parameters (or, more fundamentally, with the bending angles). The asymmetric configurations have weaker bending in B3 and B4, where the beam is shortest, which should decrease CSR effects. However, these configurations also have a larger drift between B3 and B4, which allows CSR more room to act. Simulations show a slight benefit to the asymmetric configuration for 600 A, and greater benefit beyond that. We hope to test these predictions once the flexible chambers and emittance diagnostics are fully implemented.

At present, no attempt has been made to shield CSR by placing small-gap chambers in the dipoles. Our intention is to add this feature if we find it necessary and to thus measure the effect.

5 DIAGNOSTICS

Because of concerns about CSR and jitter effects in the bunch compressor, we have planned for extensive diagnostics for the system. Although not all diagnostics are completed at this time, we expect completion this year. Figure 1 shows most of the planned diagnostics.

There are BPMs upstream and downstream of the chicane, plus one in the center of the chicane that will give information on the energy centroid. This new design is monopulse-receiver-based and should have single-shot resolution and reproducibility of 15 μm for charge of 0.1 to 2 nC.

The compressor will have a total of seven beam-imaging flags. One flag is in the chicane center, downstream of the two-blade beam scraper. Another is at the exit of B4, where a small horizontal beamsize is required to minimize CSR effects. Three flags with 1-m spacing provide a three-screen emittance measurement system. Several of these flags use a new design incorporating two cameras—one for low magnification and another for high magnification. The high magnification cameras should achieve a beam size resolution of 7 to 15 μm, depending on charge sensitivities.

The chicane bends the beam in the horizontal plane. A vertical spectrometer magnet is installed downstream of the chicane with two flags. The first flag allows imaging the $x-\delta$ correlations in the beam [5], which should give information on the effects of CSR and wakes. The second flag is used for energy spread and centroid resolution.

For bunch length measurements, we will initially use a coherent transition radiation (CTR) diagnostic [3]. This diagnostic has been successfully used with one of the TRFGs and showed features on the 100-fs scale. We have also left space for synchrotron light ports on all of the dipoles and may use this radiation for bunch-length measurements in the frequency domain [12].

6 FUTURE DEVELOPMENTS

We are also interested in use of the bunch compressor with the TRFGs. Bunch lengths of 350 fs have been obtained with one of these guns, using alpha-magnet-based compression [3]. Simulations predict that by also using the bunch compressor, bunch lengths of 5-10 fs are possible with currents on the order of 500 A. While this is not useful for FEL work, it may be useful to those interested in ultrashort pulses.

We are also planning an energy upgrade to the APS linac to allow energy of up to 1 GeV. The present limit with the bunch compressor is about 600 MeV.

7 ACKNOWLEDGEMENTS

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