GENERATION AND ANALYSIS OF SUBPICOSECOND DOUBLE ELECTRON BUNCH AT THE BROOKHAVEN ACCELERATOR TEST FACILITY*

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Abstract

Two compressed electron beam bunches from a single 60-MeV bunch have been generated in a reproducible manner during compression in the magnetic chicane - "dog leg" arrangement at ATF. Measurements indicate they have comparable bunch lengths (~100-200 fs) and are separated in energy by ~1.8 MeV with the higher-energy bunch preceding the lower-energy bunch by 0.5-1 ps [1]. Some simulation results for analyzing the double-bunch formation process are also presented.

INTRODUCTION

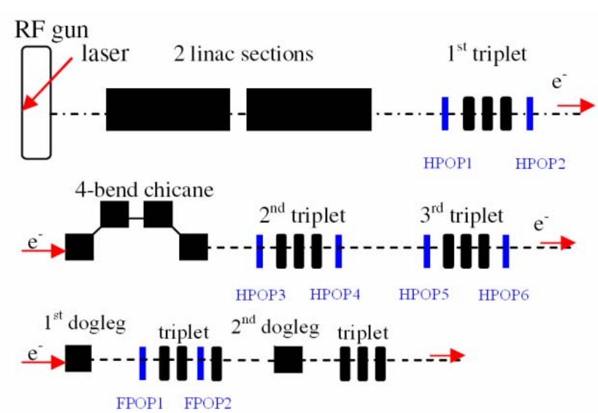
The Accelerator Test Facility (ATF) at Brookhaven National Laboratory (BNL) is a users' facility that is performing a variety of experiments related to advanced accelerator research, such as laser acceleration, generation of coherent radiation and advanced accelerator instrumentation. In support of these efforts, a chicane, designed and built by UCLA [2], was installed on the linac downstream of the RF accelerating structures. The magnetic chicaned-based compressor, where particles with different energies have different path lengths, so that a bunch with an energy distribution correlated with longitudinal particle position can shrink in length, was designed to provide approximately 30 times compression of the incoming electron bunch.

The principle problem is that short bunches traversing a dipole on curved trajectories will emit coherent synchrotron radiation (CSR). The CSR will change not only the transverse dimensions but also the longitudinal shape during the compression process. It has been reported in Ref. [3] that slight transverse phase-space bifurcation of a compressed beam was observed via the transverse phase-space tomography measurements for a compressed beam at 60 MeV. At the ATF it was also discovered when compressing the electron bunch from the linac that the beam breaks up into two distinct bunches with subpicosecond compressed bunch lengths. It does this in a consistent and reliable manner. In this paper we present the experimental results for the double-bunch formation and describe measurements for characterizing the double bunches.

The remainder of this paper gives some preliminary simulation studies to analyze the longitudinal phase space fragmentation.

EXPERIMENTAL GENERATION OF DOUBLE BUNCH BEAM

The observation of double-bunch formation is conducted at the ATF H-line [3] and the downstream two dogleg bends, where the electrons are sent to the beam line 1 at the Experimental Hall of ATF, as schematically shown in Fig. 1. The ATF H-line is composed of a photoinjector, two S-band linac sections, a four-bend chicane, six YAG-screen-based beam-profile-monitors (BPMs), and three triplets for beam focusing. The electrons are produced by a photoinjector whose photocathode is illuminated by a frequency-quadrupole Nd:YAG laser. Two S-banded (2856 MHz) linac sections are used to accelerate electrons to a maximum of 72 MeV. A four-bend C-shaped chicane, designed and built by UCLA, is used to compress bunch length down to below a picosecond (ps) with an appropriately chosen linac's rf phase. Fig. 2 shows the typical transport optics in the bending plane of chicane along the ATF chicane/dogleg region depicted in Fig. 1.



Fgure 1: Schematic of the ATF H-Line/dogleg system; the beam bends in the vertical (y) plane in the chicane.

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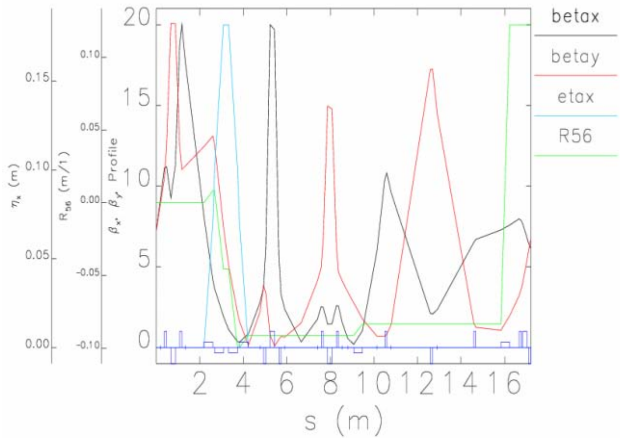

Figure 2: Transport optics in the chicane/dogleg region.

Figure 3 shows energy spectrums of the e-beam at different positions. Figure 3(a) is just before the chicane. The e-beam is a single bunch with an energy width of ~4% FWHM. Figure 3(b) is at the high-energy slit located downstream of the chicane. It shows two distinct beams with, in this particular case, most of the charge in the lower-energy bunch (energy dispersion increases to the left in the images). Figure 3(c) is at the spectrometer at the end of the beamline. The two bunches are separated by approximately 1.8 MeV [see Fig. 4(a)].

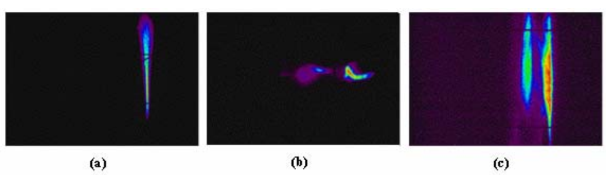

Figure 3: Raw energy spectrums of double-bunch e-beam. Energy dispersion increases to the left. (a) Before the chicane and without compression. Energy spread is ~4% FWHM. (b) At the high-energy slit located downstream of the chicane. (c) At the spectrometer at the end of the beamline.

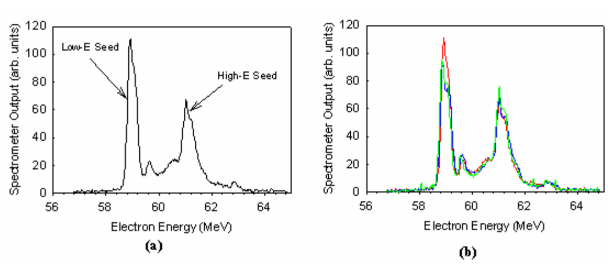

Figure 4: Energy spectrums of double-bunch e-beam. (a) Typical single shot spectrum for the case when both bunches have comparable charge. (b) Three spectrums taken many minutes apart demonstrating stability of the double-bunch formation process.

Figure 4 shows energy spectrums of the double-bunch beam. Figure 4(a) is a single shot showing the two bunches separated in energy by 1.8 MeV. Figure 4(b) is an overlay of three shots taken many minutes apart. The good reproducibility of the spectrums indicates the energy distribution and positions are very stable.

A coherent transition radiation (CTR) interferometer was used to obtain an autocorrelation of the CTR single. Analysis of this autocorrelation signal yields information about the e-beam bunch characteristics [4]. Figure 5 shows an example of the autocorrelation data and the curve fits derived from the autocorrelation integrals for the double-bunches. There are five free parameters in the autocorrelation integral. Using CTR and beam position monitor (BPM) data for each bunch of the double bunches permits reducing the number of free parameters to two, i.e., the time delay between the two bunches and the cut-off frequency. For the curve fit shown in Fig. 5, we find the time delay between the bunches is 500 fs and the cut-off frequency is 1.8 THz.

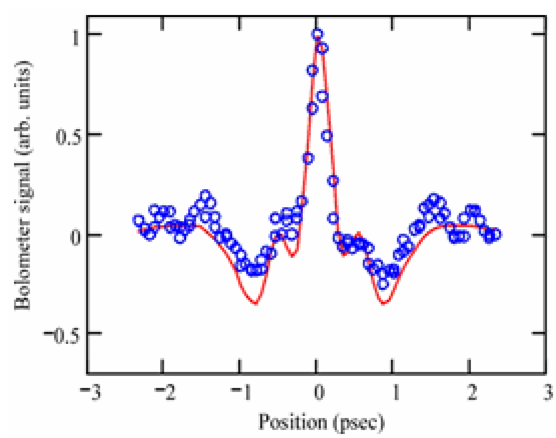

Figure 5: Example of raw data from CTR interferometer (circles) and the curve fits to the data (solid line) calculated from the autocorrelation integral.

SIMULATION AND ANALYSIS OF DOUBLE BUNCH GENERATION

Coherent synchrotron radiation is expected to play an important role in the fragmentation of longitudinal phase space. For example, similar features of this longitudinal phase space fragmentation have been observed at the TESLA test facility [5]. It has been self-consistently simulated with the code TraFiC4 [6] and explained by strong enhancement of CSR effects due to the locally peaked (non Gaussian) density distribution created during compression process because of RF non-linearity. In this section we report our preliminary simulation results by using some CSR tracking codes (e.g. Elegant [7] and CSRTrack [8]) for the analysis of the double-bunch formation. The code Elegant calculates the CSR fields with the 1D projected method. The code CSRTrack tracks 3D sub-bunches through a beam line consisting only of drifts and horizontal bending magnets. The field calculation can be either the 1D projected method, the 2D Green's function method or the 3D convolution method.

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Table 1 lists the basic parameters of our bunch beam and four-bend chicane in the simulation.

Table 1: Parameters of chicane and beam used in the simulation

Bend magnet length	0.41 m
Drift length, B1-B2 and B3-B4	0.08 m
Drift length, B2-B3	0.24 m
Bend angle	20 deg
Bend radius	1.2 m
Momentum compaction	-88 mm
Bunch charge	0.5 nC
Electron energy	60 MeV
Bunch length (in)	300 μm
Bunch length (out)	45 μm

Preliminary results of this simulation are given in Fig. 6 with the program elegant and Fig. 7 with the code CSRTrack. Figure 6(a) shows an example of the beam entering the chicane with a curved energy chirp because of the non-linearity of the accelerating RF fields. Figure 6(c) gives the resultant momentum-time distribution of the electrons after the dogleg. It is clear there has been a separation in energy of the electrons with a large group congregated in the lower half of the plot and a smaller group in the upper half. Elegant also indicates this separation in energy does not occur if CSR effects are turned off in the model. Fig. 7 shows the longitudinal profile and bunch current distribution before and after the compression. We see that the longitudinal phase space folds over and most of the charge accumulates at the head of the bunch under the non-linearity of longitudinal dispersion in the chicane without considering the effect of sinusoidal RF curvature and assuming a linear chirp entering the chicane.

Because the code TraFiC4 can track the full 6D phase space coordinates of the sub-bunches with an arbitrary orientation space, to better understand the complicated beam energy profile, we plan to use TraFiC4 to simulate the beam through ATF chicane/dogleg region where chicane and doglegs are in the vertical plane and horizontal plane, respectively.

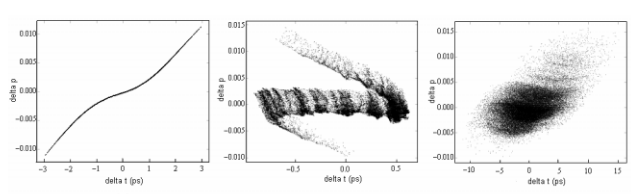

Fig. 6: Longitudinal phase space from the program elegant of the chicane/dogleg system. (a) Momentum-time plot of electrons entering the chicane. (b) Momentum-time plot of electrons leaving the chicane. (c) Momentum-time plot of electrons at exit of 2nd dogleg.

CONCLUSION

The non-linearities of both the accelerating RF fields and the longitudinal dispersion are probably the reason that distorts the longitudinal phase space and generates the double-bunch beam. Unlike other facilities that are utilizing a chicane for pulse compression, the ATF does not have a subsequent 3rd harmonic RF system downstream of the chicane [9], which can be used to compensate for residual energy chirp on the electron beam (e-beam) exiting the chicane. We believe the longitudinal phase space can be linearized and this double-bunch formation process will not occur once an X-band acceleration section is installed downstream of the chicane in the near future at the ATF.

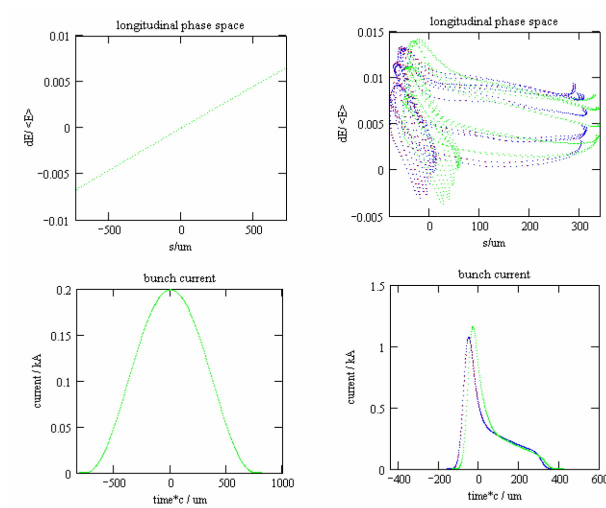

Fig. 7: Longitudinal phase space and bunch current distribution given by the code CSRTrack with the 1D projected method (green points) , the 2D Green's function method (blue points) and the 3D convolution method (red points) before (left two plots, blue and red behind green) and after the bunch compressor chicane (right two plots, red behind blue).

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