Magnetic Pulse Compression Using a Third Harmonic RF Linearizer*

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Abstract

A scheme for compressing 4 nC, 55 ps long bunches to 7 ps at 18 MeV uses, in addition to a magnetic chicane, a third harmonic RF section serving the dual functions of (1) removing the nonlinear distortion placed on the bunch by the upstream linac and (2) impressing on the bunch the linear energy slew required for compression in the chicane. The performance improvement expected from using the linearizer is estimated using an heuristic model based on bunching experiments[1].

Introduction

Electron beam applications, such as free electron lasers, require electron beams with both low emittance and high peak current. While the RF photocathode injector has demonstrated excellent beam quality, the emittance has been observed to grow as the micropulse charge (and hence the peak current) at the photocathode is increased. For the injector discussed in this paper the rms emittance increases at the rate of 1.1 π mm mrad per nanocoulomb of charge[2]. This emittance growth can be controlled by beginning with a long, but high charge micropulse with a low peak current in the injector, and then, when the beam is relativistic, compressing it in a non-isochronous bend.

In this scheme the compression factor, the ratio of the before and after pulse lengths, is limited by the non-linearities introduced by RF and space charge forces. The space charge effects are already reduced by limiting the peak current at the cathode and are included by using the results of a longitudinal emittance experiment. The accelerating RF waveform introduces a curvature to the longitudinal phase space. This paper discusses the use of a third harmonic accelerator section to both linearize the phase space to increase the compress factor, and to impress the required energy slew for compression in a three dipole chicane.

Description of the Experiment

The layout of the Boeing 18 MeV photoinjector accelerator is shown in Figure 1 [3]. The accelerator consists of a 433 MHz, two cavity injector using a K_2CsSb photcathode driven by a frequency doubled Nd-YLF mode-locked laser[4]. The energy after the injector cavities is 2 MeV. This is followed by four 433 MHz accelerator sections which accelerate the beam to 18 MeV. Besides quadrupoles and electron beam diagnostics, the beamline consists of the third harmonic linearizer (a 1300 MHz accelerator section), a three dipole chicane buncher and an electron beam dump.

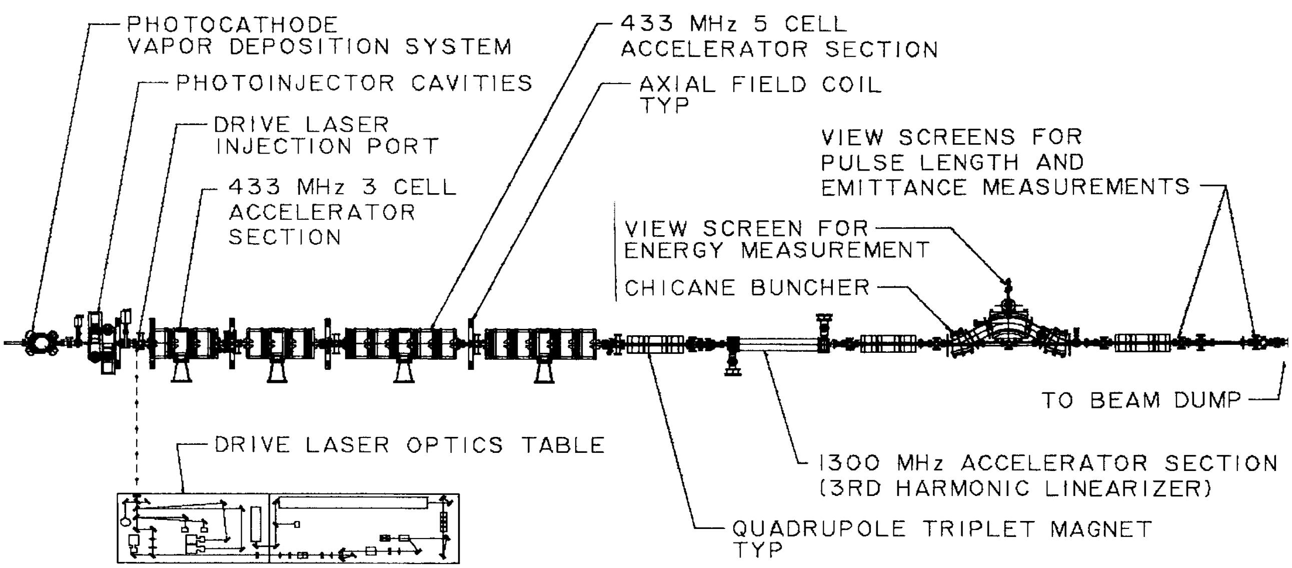

Figure 1. Accelerator configuration showing the injector cavities, 433 MHz accelerator sections, the 1300 MHz third harmonic linearizer and the three dipole chicane buncher.

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The object of this experiment is to determine the pulse compression factors both without and with the linearizer in operation. This is done by measuring the pulse length after the chicane with a streak camera, and the energy spread at the view screen in middle dipole of the chicane, first using the 433 MHz sections and then the linearizer to produce the energy slew.

Calculation of Beam Compression

The compression factor is calculated by beginning at the exit of the injector cavities and using the following relations to transform the beam's longitudinal phase space through the accelerator sections and the chicane. Since the phase space is distorted by non-linear effects it is necessary to perform a ray tracing calculation[1].

In terms of the initial paraxial longitudinal coordinates ΔE_0 and Δt_0, the accelerator transformation is

$$\Delta E_1 = E_{433}\,[\cos(\omega_{433}\,\Delta t_0 + \phi_{433}) - \cos\phi_{433}] + \Delta E_0$$
$$\Delta t_1 = \Delta t_0$$

Here E_{433} is the peak energy gain in the 433 MHz accelerator sections and ϕ_{433} is the micropulse synchronous phase relative to the accelerating peak of the 433 MHz waveform. Similar relations transform the beam through the 1300 MHz linearizer, so that at the entrance to the bunching chicane the transformation is

$$\Delta E_2 = E_{1300}\,[\cos(\omega_{1300}\,\Delta t_1 + \phi_{1300}) - \cos\phi_{1300}] + \Delta E_1$$
$$= E_{1300}\,[\cos(3\omega_{433}\,\Delta t_0 + \phi_{1300}) - \cos\phi_{1300}] + E_{433}\,[\cos(\omega_{433}\,\Delta t_0 + \phi_{433}) - \cos\phi_{433}] + \Delta E_0$$

$$\Delta t_2 = \Delta t_1 = \Delta t_0 \quad .$$

The 1300 MHz RF voltage is adjusted so that its second derivative exactly cancels that of the 433 MHz waveform; i.e., so that

$$\left.\frac{d^2\Delta E_2}{d\Delta t_2^{\,2}}\right|_{\Delta t_2=0} = 0 .$$

This condition is obtained when

$$E_{1300}\cos\phi_{1300} = -\frac{E_{433}\cos\phi_{433}}{9},$$

or when the third harmonic section *removes* 1/9 of the beam energy, or 2 MeV. Generally, $\phi_{433} = 0$, and ϕ_{1300} is chosen to provide the temporal ramp required for bunching in the chicane, where the transformation is

$$\Delta E_3 = \Delta E_2$$
$$\Delta t_3 = \delta\,\Delta E_2 + \Delta t_2 ,$$

δ being the longitudinal non-isochronicity of the chicane (for our chicane, δ = 50 ps/MeV). For the tightest possible bunching, we would require an end-to-end energy slew of 1.1 MeV over the 55 ps duration of the bunch in order to collapse the bunch completely. This requires

$$E_{1300}\sin\phi_{1300} = 2.45 \text{ MeV}.$$

Given that

$$E_{1300}\cos\phi_{1300} = 2 \text{ MeV},$$

we have

$$E_{1300} \simeq 3.2 \text{ MeV}, \qquad \phi_{1300} \simeq 50^{\circ}.$$

The calculation begins at the exit of the injector cavity and the initial phase space is obtained from the experiment performed at the ELSA FEL facility at Bruyeres-le-Chatel, France[1,5]. In this experiment the uncorrelated energy spread of the injector beam was observed to increase from 14 KeV to 22 KeV as the peak current density at the photocathode was increased from 200 A/cm^2 to 400 A/cm^2 with negligible pulse length elongation. For our case of 4 nC and 55 ps, the peak current density is 237 A/cm^2. Therefore the uncorrelated energy spread after the injector is estimated to be 15 KeV.

The longitudinal phase space beginning at the injector cavity exit and its transformations to the entrance and exit of the chicane are shown in Figure 2. The curvature distortion due to the 433 MHz waveform is most evident at the chicane exit where the phase space has been rotated to bunch the beam. Figure 3 shows the compressed phase space with the third harmonic linearizer in use. The s-shape is due

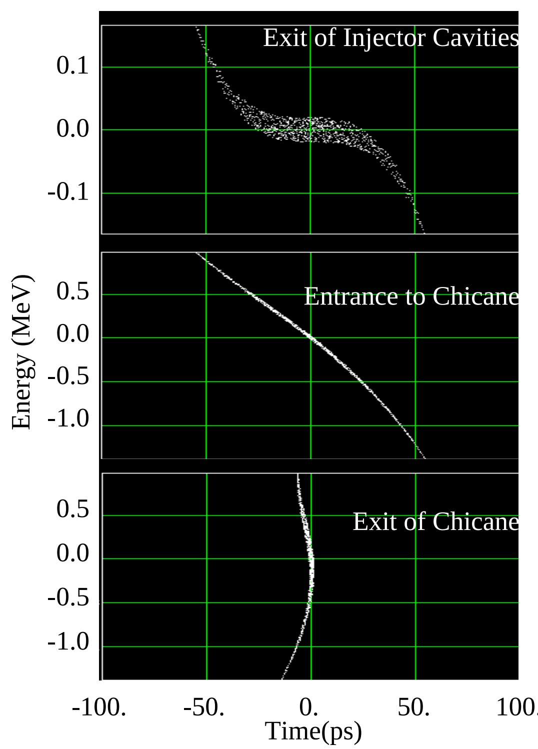

Figure 2. Evolution of the longitudinal phase space during compression without the linearizer.

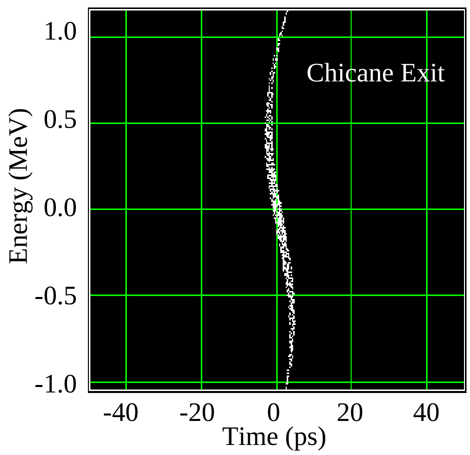

Figure 3. Longitudinal phase space after the chicane when the beam is linearized and compressed.

to space charge distortion in the injector and is the result of the data analysis in Reference 1.

The projections of the compressed phase spaces onto the time-axis are given in Figures 2 and 3 are shown in Figure 4. While the non-linearized beam has a smaller FWHM,

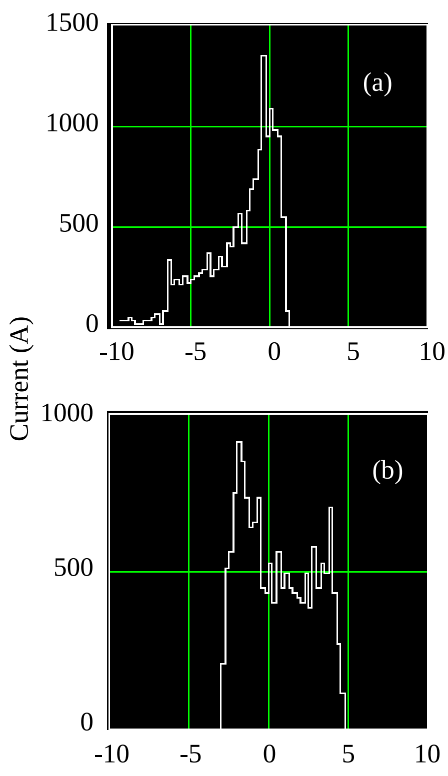

Figure 4. Comparison of the compressed electron beam pulse shapes without (a) and with (b) the phase space linearized.

it has a long tail reducing the number of well bunched electrons by approximately half. In contrast, the linearizer produces a square pulse shape of nearly constant peak current.

Conclusions

Using a third harmonic RF linearizer before a three dipole chicane buncher generates a nearly flat-topped 4 nC electron beam pulse 7 ps wide with a peak current 500 A. This square pulse shape makes efficient use of the electrons and leads to improved performance of devices such as free electron lasers[6].

References

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