CHICANE RADIATION MEASUREMENTS WITH A COMPRESSED ELECTRON BEAM AT THE BNL ATF

G. Andonian, R. Agustsson, A. Cook, M. Dunning, E. Hemsing, A. Murokh,
S. Reiche, J. Rosenzweig
UCLA, Los Angeles, California, USA
M. Babzien, K. Kusche, R. Malone, V. Yakimenko
BNL, Upton, New York, USA

Abstract

The radiation emitted from a chicane compressor has been studied at the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF). Coherent edge radiation (CER) is emitted from a compressed electron beam as it traverses sharp edge regions of a magnet. The compression is accompanied by strong self-fields, which are manifested as distortions in the momentum space called beam bifurcation. Recent measurements indicate that the bunch length is approximately 150 fs rms. The emitted THz chicane radiation displays strong signatures of CER. This paper reports on the experimental characterization and subsequent analysis of the chicane radiation measurements at the BNL ATF with a discussion of diagnostics development and implementation. The characterization includes spectral analysis, far-field intensity distribution, and polarization effects. Experimental data is benchmarked to a custom developed start-to-end simulation suite.

INTRODUCTION

The chicane compressor experiment, located at the Accelerator Test Facility (ATF) in Brookhaven National Laboratory (BNL), is a joint UCLA-BNL collaboration designed to investigate the properties of radiative processes of electron beams through bending magnets. Compressors are commonly used, and proposed, for experiments requiring high-brightness, high-current applications. One such experiment is the Linac Coherent Light Source (LCLS), which will employ similar compression schemes to achieve the appropriate conditions (high-current, short bunch length, low energy spread) for generating Ångstrom x-ray radiation [1]. The motivation for the UCLA-BNL project is to extensively characterize the compression and radiation processes of relativistic electron beams undergoing bends, with an emphasis on coherent edge radiation.

The process of compression brings about strong beam self-interactions which lead to radiation processes such as coherent synchrotron radiation (CSR). The CSR emitted from bend magnets has been previously studied and distortions of phase space have been commonly observed [2]. A radiative process that has been observed [3] but yet to be fully examined, is that of coherent edge radiation (CER), or the radiation resultant from a relativistic electron beam traversing the sharp edge of a magnet. CER is contrasted to CSR in a number of ways. First, CER is radially polarized similar to coherent transmission radiation (CTR), whereas CSR is linearly polarized along the bend plane of the dipole. Second, at long wavelengths (compared to the bunch length of the beam) the total energy emitted by CER is dominant over CSR [4]. The UCLA-BNL chicane compressor experiment is an ideal place to study the CER effect and a number of measurements have been undertaken to characterize the radiation emitted (CER and CSR) from the chicane compressor. The results of this experiment are of particular interest to the development of non-destructive bunch length monitors, as the emitted CER contains information regarding the longitudinal distribution of the beam profile, and the detector can be placed away from the beam trajectory. Also, these initial results are of interest to CER as a unique source of terahertz radiation which is emerging as a viable candidate for numerous scientific and industrial, imaging and probing applications.

Table 1: ATF Chicane Compressor Parameters

Chicane Specifications	
Bend Field	1.7 kG
Bend Angle	20 deg
Radius of Curvature	1.2 m
Orientation	Vertical
ATF Beam Parameters	
Energy	61 MeV
Charge	300 pC
Normalized Emittance	2.0 mm-mrad

EXPERIMENT DESCRIPTION

The ATF is capable of producing high-brightness beams, of varying energy and chirp with an rf photoinjector and two linacs. The typical beam parameters used for the chicane compression experiments are listed in Table 1. The chicane compressor is a four dipole magnetic array, located downstream of the ATF photoinjector. The chicane has a peak field of just under 0.2 T, with a radius of curvature of 1.2 m [5]. The chicane was designed and modeled, and the field quality was, subsequently, mapped and measured at the UCLA Particle Beam Physics Laboratory.

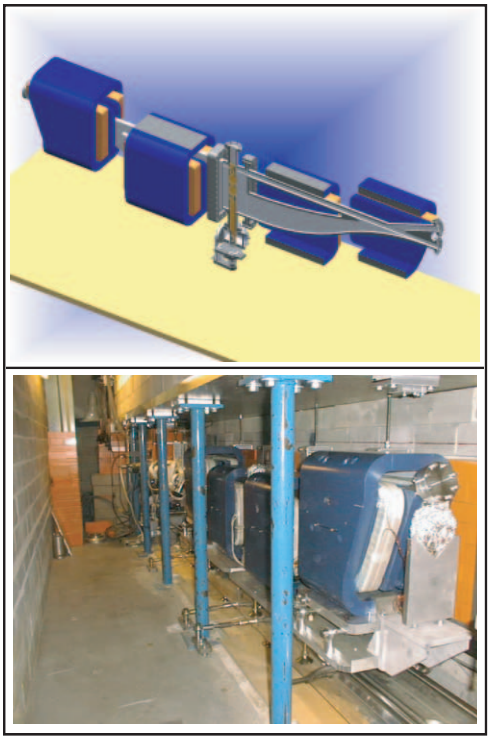

Figure 1: 3-dimensional chicane rendering with cross-sectional cutaway displaying the CER extraction port (top). Installation of chicane compressor along the ATF beamline, downstream of the linac (bottom).

During compressor operations, an energy chirp (energy-time correlation) is imparted onto the electron bunch at the photoinjector. The chirp allows for a change in the time of flight of the particles of the beam, effectively shortening the bunch length of the beam, thereby increasing the current. With the UCLA chicane parameters (Table 1), the beam current is designed to increase from the nominal 60 A to approximately 300 A (the bunch length shortened to ≈30 microns).

Transport and Diagnostics

The CER is emitted from the exit of the 3rd dipole and entrance of the 4th dipole magnets of the chicane. The chicane radiation is collected via an extraction port located at 20 degreees on the vacuum enclosure. The radiation is transported through 3 inch diameter aluminum tubes, with Picarin lenses placed at the appropriate focal points. The 7-m long transport incorporates two bends (metal mirrors) and a final focusing mirror (gold off-axis parabola) to direct the radiation to the diagnostic station.

The diagnostic station is located adjacent to the high energy beam line, which allows for manageable manipulation of the extracted radiation. There are multiple diagnostics in use for the chicane compression studies.

A liquid helium cooled, Silicon bolometer is the main detector used to characterize the radiation. The bolometer is ideal in this application because its signal response is frequency independent (spectrally flat); it is also very sensitive to minor changes in temperature allowing for measurements of very weak signals. The bolometer incorporates a filter wheel, with different cut-on filters to examine the radiation up to the terahertz regime. In tandem with the bolometer, a wire-grid polarizer mounted on a rotatable stand, is used to characterize the polarization of the incoming chicane radiation. A calibrated aperture is mounted on a two dimensional stage to measure the far-field angular distribution pattern of the radiation. Finally, a Michelson-type interferometer is used in conjunction with the bolometer to autocorrelate the chicane radiation for spectral analysis.

The radiation diagnostics are complemented by electron beam diagnostics located downstream of the chicane. Initial bunch length measurements used the Michelson-type interferometer;the interferometer was placed inside the high energy tunnel and the CTR emitted from an insertable foil was used to determine the longitudinal profile. The beam momentum spectrum is measured with a dipole spectrometer downstream of the chicane, in conjunction with slits and a scintillating screen (Figure 2 for example). Transverse phase space studies are made using tomographic techniques developed by the ATF [6].

Start-to-End Simulation

The start-to-end simulation suite developed for the compressor studies involves UCLA PARMELA [7] for the gun and linac acceleration processes and QUINDI for the radiative processes in the chicane. The numerical code QUINDI was developed to enhance the understanding of the complex processes that take place during compression [8]. QUINDI obtains the macroparticle trajectories through the chicane using only the applied magnetic forces; the trajectories are used to calculate the radiation fields using the Lenard-Wiechert formalism, neglecting self-interaction forces to allow large numbers of simulation particles.

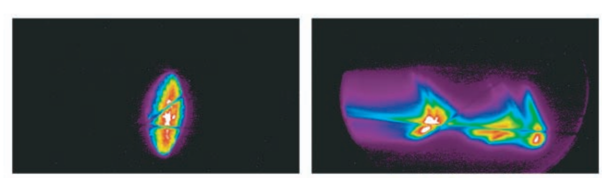

Figure 2: Momentum spectrum of the electron beam at minimum energy spread (left) and fully compressed with clear signs of bifurcation (right). Images taken with the ATF dipole spectrometer

MEASUREMENTS AND ANALYSIS

Compressed beams at moderate energy display longitudinal phase space breakup. This beam breakup is apparent in the momentum space beam breakup, referred to as bifurcation, measured at the ATF with the dipole spectrometer

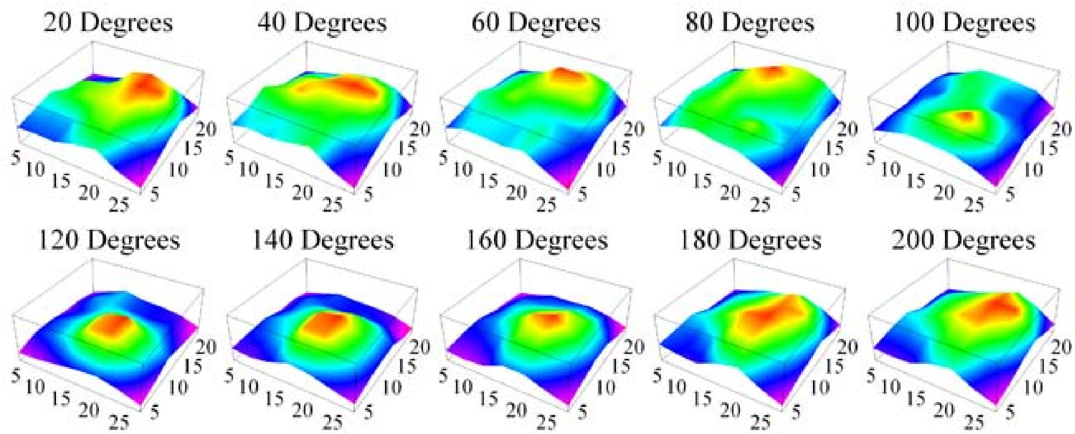

Figure 3: Experimental far-field angular intensity distributions of emitted chicane radiation as a function of polarizer angle. Transverse dimensions have units of mm.

(Figure 2). The bifurcation observed is used as an online optimizing tool, as the maximum emitted CER radiation corresponds to a bifurcation of the beam momentum space when the beam is fully compressed. Figure 2 shows the electron beam via the dipole spectrometer at minimum energy spread (about 9 degrees forward of rf crest) and fully compressed (about 19 degrees forward of crest).

An analysis of the CTR emitted from an insertable foil was conducted. The CTR signal was autocorrelated by the interferometer and subsequently analyzed to yield longitudinal bunch information. Once autocorrelated, the signal is Fourier transformed to give the intensity spectrum. Imposing asymptotic behavior, the form factor is achieved and used with the Kramers-Kronig analysis to retrieve the phase and longitudinal profile [9]. Following this analysis, a bunch length of 150 fs rms (45 micron rms) was demonstrated for the compressed beam.

The emitted radiation from the compressed beams was collected and analyzed. The wire grid polarizer, rotated in increments of 15 degrees, verified the presence of both CER and CSR. The CSR, which is linearly polarized in the bend plane, exhibits sinusoidal dependence on the polarizer angle, whereas the CER, which is radially polarized, shows no dependence on the polarizer angle [10]. In practice, the CER appears as an offset to the sinusoidal curve when the polarizer is rotated in front of the detector.

The terahertz spectrum of the CER was measured using the autocorrelation signal and the results are reported elsewhere [10]. Complementary to the radiation spectrum, the far-field angular intensity distribution was measured with respect to polarization. The results of this study are displayed in Figure 3. The intensity distribution includes a notable trend which shows one dominant mode smearing out into multiple modes with varying polarization angle. This trend is indeed verified by the simplified QUINDI simulations, although the exact dependence on polarization includes some discrepancies which will be addressed in future iterations of the code.

CONCLUSIONS

The chicane compressor has successfully been commissioned at the BNL ATF. Using a Kramers-Kronig analysis of the autocorrelation of the emitted CTR [9], a bunch length of 45 micron rms was demonstrated. Accompanying, the compressed bunch was a momentum space beam bifurcation consistent with maximum radiation emitted from the chicane at the 20 degree extraction port. The emitted radiation displays telling signatures of coherent edge radiation, including trademarks such as radial polarization and terahertz spectrum. The measurements were benchmarked to the code QUINDI with reasonable agreement.

Forthcoming improvements to the experiment are imminent and include the installation of a Z-cut quartz windows and evacuation of transport tubes to improve signal quality at the detector. The evidence of CER in this experiment will be useful in other applications including real-time online bunch length diagnostics or also as use as an exotic terahertz source for other endeavors.

REFERENCES

[1] M. Cornacchia, *et al.*, Linac Coherent Light Source Design Report No. SLAC-R-521 (1998)

[2] T. Nakazato, *et al.*, Phys. Rev. Lett. 63, 1245 (1989)

[3] A. S. Muller, *et al.*, Proc. Particle Accel. Conf. '05, Knoxville, TN (2005)

[4] O. V. Chubard and N. V. Smolyakov, J. Optics 24, 117 (1993)

[5] R. Agustssson, Ph.D. Dissertation, UCLA, (2004)

[6] F. Zhou, *et al.*, Phys. Rev. ST Accel. Beams **9**, 114201 (2006)

[7] L. M. Young and J. H. Billen, LANL Accel. Code Group Tech. Report No. LA-UR-96-1835 (rev. 2000)

[8] D. Schiller, *et al.*, Presented at these Proceedings

[9] R. Lai and A.J. Sievers, Phys. Rev. E 84, 658 (1994).

[10] G. Andonian, *et al.*, Presented at the BNL ATF User's Meeting (2007)

