GENERATION AND CHARACTERIZATION OF THE MICROBUNCHED BEAMS IN THE RANGE FROM 0.3 TO 500 FEMTOSECONDS

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Abstract

The recent results include formation and measurement of the micro bunch structures of the different time scales. Double beam structure produced and characterized at 100 fs – 0.5 ps range using beam splitting during compression in the magnetic chicane – “dog leg” arrangement. Arbitrary number of 10-50 femtoseconds micro bunches are sliced out of 5 ps long beam using wire mesh. CSR interferometer is used for detailed characterization of the beams in the two techniques above. 0.3 fs bunches are produced by IFEL and characterized by spectral measurements of the multiple harmonics. Presentation covers experimental results at Brookhaven Accelerator Test Facility.

INTRODUCTION

Three distinct experimental methods are discussed in this paper in the following 3 chapters. The first one discusses measurements of micro bunched beams generated with CO2 laser in the IFEL wiggler. Comparison of the coherent transition radiation CTR power in multiple harmonic leads to much more precise information about micro bunch length. The second part of the paper discuses generation of micro bunched beams that are not seeded with laser. Wire mesh targets were shaping the beam in the dispersive region and converting correlation between energy and time into current time modulation. Tunable spacing is the result of this technique. We used an interferometer to characterize these beams. The last chapter of this paper discusses controllable beam break up into two beam structure. The two beam formation happens during its compression in the magnetic chicane – dog-leg combination. Effects of the space charge and CTR are very important and stabilize the process contrarily to initial expectations. We used interferometer and plasma wakefield capillary to characterize two 100 fs bunches formed in this process.

CHARACTERIZATION OF SUBMICRON MICROBUNCHES PRODUCED BY IFEL WITH CTR IN MULTIPLE HARMONICS

We collect the coherent transition radiation (CTR) emitted when the microbunches traverse two 1μm thin titanium metal foils in order to diagnose the quality of the microbunching of the IFEL modulated electron beam. CTR is emitted because the electric fields of the electrons in the beam displace violently the free electrons in the metal surfaces, which in turn radiate due to the acceleration they suffer.

The first metal foil is placed perpendicularly to the beam direction of propagation and serves the purpose of blocking the CO2 radiation previously used at the IFEL interaction that could interfere with the CTR signal. The second foil is placed at 45^{o} with respect to the direction of propagation and emits radiation out of the beamline. The sum of the radiation emitted from both foils is collected.

The spectrum of the CTR radiation contains information about the geometry of the electron beam. The on axis spectrum is proportional to the amplitude squared of the Fourier transform of the beam and shown on figure 1.

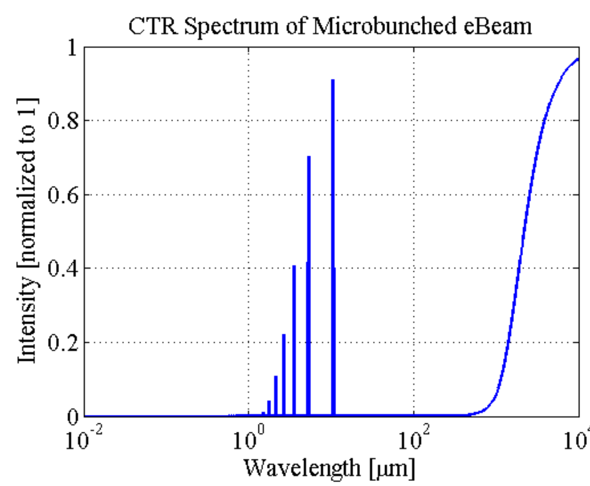

Figure 1. The spectrum of the CTR emitted when the microbunched electron beam passes through a metal foil.

The geometry of the electron beam is uniquely mapped into its CTR spectrum. The low frequency (long wavelength) radiation on the right corresponds to the envelope of the beam. In other wavelengths the radiation in general adds out of phase except at the harmonics of the separation wavelength λ_0=10.6μm between the microbunches.

Finally and most importantly, the amplitudes of these harmonics are modulated by the Fourier transform of each microbunch. The existence of radiation at each harmonic is a strong indication for the periodicity of the microbunch train. Also, the energy radiated at each harmonic depends on the shape of each microbunch, hence it provides a direct way of estimating its width, which is assumed to be Gaussian in this case.

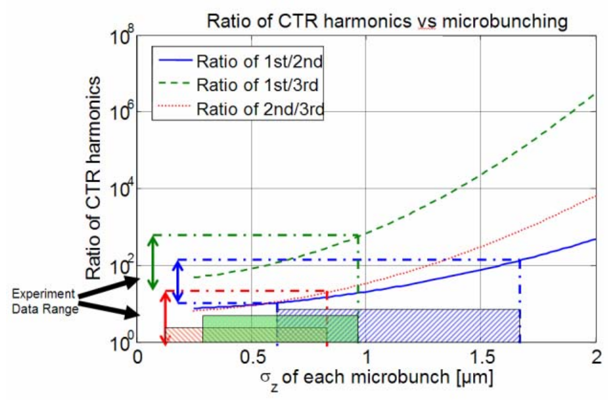

Figure 2. The ratios of the energies radiated at each of the harmonics as a function of microbunch width. The 3 data sets agree at the region around σ_z=0.7μm .

In order to collect the CTR, a cold detector sensitive between 3μm-20μm wavelengths is used. Furthermore, narrow Gaussian bandpass filters with roughly 5% FWHM transmission bandwidth were used to isolate the radiation of the first, second and third harmonic, in successive measurements. After recording about 100 events at a roughly constant IFEL laser pulse energy (within a factor of 2) at all three harmonics, we calculated the three possible ratios of the harmonics signals. The data range for each ratio is shown on the vertical axis on figure 2.

Using prediction for small angles and after accounting for the response of the detector and the filters calibrated with the black body source, we calculated the expected theoretical ratio between the energy radiated under each of the harmonics as a function of the microbunches' widths. These three predicted ratios also are plotted in figure 2. It shows that the measured rations indicate a width of σ_z=0.7μm for each microbunch. Although the microbunch width was inferred using CTR [1] and staged laser accelerator [2] before, this is its first direct measurement that also utilizes information from different harmonics.

In order to confirm the 10.6μm separation between the microbunches the IFEL laser was tuned at 10.2μm, while still using the same narrow 10.6μm filter to detect the CTR. In that case the signal recorded was at least 100 times less than when the IFEL was driven at 10.6μm and very close to the noise level of the detector, thus confirming the periodicity of the bunching at the laser's wavelength only.

TUNABLE MICROBUNCH TRAIN

The microbunched beam described above offers stable, well defined by spacing the laser. It is a disadvantage if the laser in not easily available in the range that is needed. We attempted to use a periodic wire mask installed at the dispersive region of the beam transport to generate microbunches with the spacing that is determined by the target period. The idea is very simple: a beam is chirped in the linac and therefore energy-time correlation is introduced. The target is installed in the location where dispersion is large while betatron size in the plane of the dispersion is smaller then target period. This effectively creates time-current modulation. We use 125-500μm diameter wire to make targets. Low emittance 50 MeV beam is effectively scattered by this wire. The photograph of the taget is shown on figure 3.

Figure 3. Photograph of the wire target for adjustable microbunch beam generation.

One can clearly see modulation in of current vs energy on the electron beam energy spectrometer. It is even possible to see unintentional defect of the target "double wire" approximately in the middle of the beam.

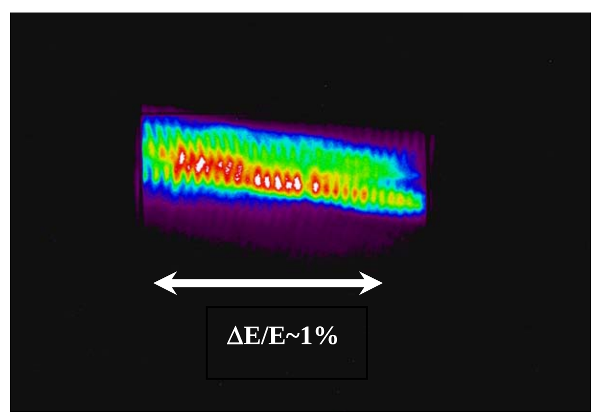

Figure 4. Image from the beam energy spectrometer. It shows 15 microbunches stretched over ~1% energy chirp induced on the beam.

The translation of the microbunch spacing from target period naturally depends on the chirp and dispersion value at the target location. We operated with a set of parameters where it is adjustable 10: target with 250 μm period will generate microbunches spaced by 25 μm. We use a pair of installed before target sextupole magnets to linearize or chirp the spacing between micro bunches. High energy slit opening that controls energy spread envelope of the beam can be used to select arbitrary number of microbunches. The demagnification can be adjusted by change of dispersion, beam chirp or target rotation.

CTR interferometer [4] was used to measure modulation in time. Our attempt to measure individual microbunches with the period of ~25-30 µm did not produce the expected result due to cutoff of the window transmission around 30 µm. The signal strength on the detector increased considerably for the modulated beam. The interference showed expected envelope of the beam Interference curve was triangular that translates to the “square’ beam envelope. (Tails of the beam were cat by high energy slip.)

We detected individual bunches with correct periodicity after switching to the 1mm target and retuning transport line for 1:5 demagnification. Interferogram is shown on figure 5.

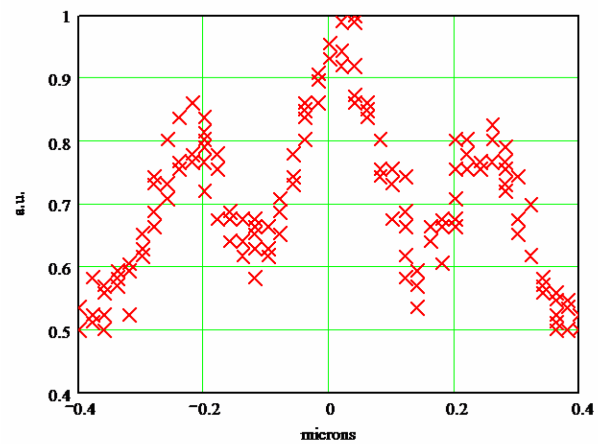

Figure 5. Interferogram of the microbunched beam generated with the periodic wire target.

SUBPICOSECOND DOUBLE ELECTRON BUNCH GENERATION

As part of these efforts towards improving beam for various experiments related to advanced accelerator research, a chicane, designed and built by UCLA [1], was installed on the linac downstream of the RF accelerating structures. The chicane was designed to provide approximately 30 times compression of the incoming electron bunch. Figure 6 is a diagram of the chicane.

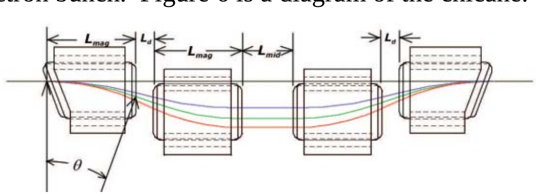

Figure 6. Diagram of ATF chicane.

It was discovered that 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. Unlike most of other facilities that are utilizing a chicane for pulse compression, the ATF does not have a subsequent RF acceleration section downstream of the chicane, which can be used to compensate for residual energy chirp on the electron beam (e-beam) exiting the chicane. Not being able to use a downstream acceleration section was one reason the double-bunch formation process was possible.

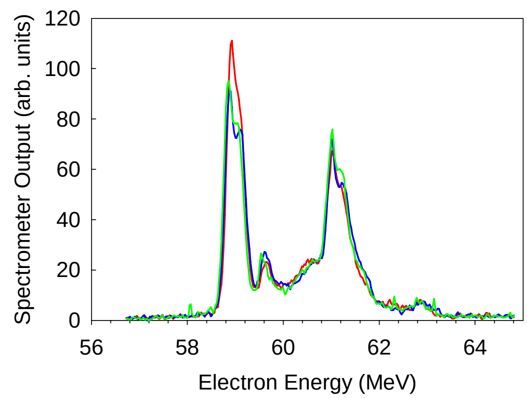

Figure 7. Energy spectrums of double-bunch e-beam. Three spectrums taken many minutes apart demonstrating stability of the double-bunch formation process

Figure 7 shows energy spectrums of the double-bunch beam. It shows two bunches separated in energy by 1.8 MeV. It 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 characterize the compressed e-beam. The CTR emission is in the THz range. An autocorrelation of the CTR signal is obtained by scanning the translation mirror shown in Figure 8

Analysis of this autocorrelation signal yields information about the e-beam bunch characteristics [4].

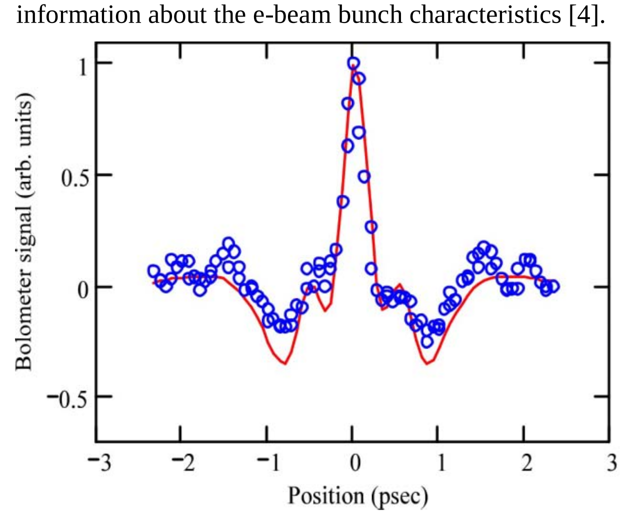

Figure 8: Example of raw data from CTR interferometer (circles) and the curve fits to the data (solid line) calculated from the autocorrelation integral [2]. “Bumps” around +- 0.5 ps indicate double bunch spacing.

For a single bunch, the curve fit of the autocorrelation integral with the data requires selecting values for the bunch length and the cut-off frequency of the detection system, where we have assumed a Gaussian bunch shape. In particular, the width of the central peak of the autocorrelation signal is primarily affected by the bunch length. The shape of the curve on either side of the peak is mostly affected by the cut-off frequency.

For a double e-beam bunch, there are five free parameters in the autocorrelation integral. We were able to characterize each bunch individually using CTR and beam charge monitor. Single bunch data was obtained by using the high-energy slit located downstream of the chicane to block one of the bunches (either the low-E or high-E bunch). Individual bunch data for each bunch of the double bunches permits reducing the number of free parameters to one, i.e., the time delay between the two bunches. For the example shown in Figure 8, the single-bunch CTR data indicates the lengths of the two bunches is 144 and 90 fs, the cut-off frequency is 1.7 THz, and the second bunch has 60% of the charge in the first bunch. Hence, for the curve fit shown in Figure 8, we find the time delay between the bunches is 500 fs.

Results of simulations with Elegant [5] confirmed our hypothesis that double beam structure is cased by the combination of nonlinear energy chirp and different sign of compression in the chicane and dog leg. Self induced beam wakes narrowed energy spread in the beam and let to complete separation.

ACKNOWLEDGMENTS

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