DEVELOPMENT OF A VERSATILE BUNCH-LENGTH MONITOR FOR ELECTRON BEAMS AT ASTA*

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Abstract

We have installed a versatile bunch length monitor system at a location after the chicane in the ASTA beamline. Options for generating radiation from a metal screen and transporting coherent radiation to the Martin-Puplett Interferometer and optical transition radiation to a synchroscan streak camera are provided. There is also a chicane bypass line so this station can evaluate the uncompressed beam as well. The system will be used to characterize the bright beams of the photoinjector.

INTRODUCTION

The generation of bright electron beams at the Advanced Superconducting Test Accelerator ASTA/IOTA facility [1] at Fermilab has motivated implementation of a versatile bunch-length monitor located after the 4-dipole chicane bunch compressor for electron beam energies of 20-50 MeV and integrated charges in excess of 10 nC. The station includes both a Hamamatsu C5680 synchroscan streak camera and a Martin-Puplett interferometer (MPI). An Al-coated Si screen will be used to generate both optical transition radiation (OTR), coherent transition radiation (CTR), and coherent diffraction radiation (CDR) during the beam's interaction with the screen. A chicane bypass beamline will allow the measurement of the bunch length without the compression stage at the same downstream beamline location using OTR and the streak camera. The UV component of the drive laser has previously been characterized with a Gaussian fit sigma of 3.5 ps [2], and the uncompressed electron beam is usually expected to be similar to this value at low charge per micropulse. Elongation of the pulse to >15 ps at 250 pC per micropulse has been recently predicted [3]. In addition, OTR will be transported to the streak camera from the focal plane of the downstream spectrometer to provide an E-t distribution within the micropulse time scale. This application relies heavily on the synchronous sum of micropulses in order to obtain an image with adequate statistics. Commissioning of the system and initial results with beam will be presented.

EXPERIMENTAL ASPECTS

The high-power electron beams for the ASTA/IOTA facility [1] were generated in a photoinjector based on a UV drive laser and the L-band rf photocathode (PC) gun cavity. The system has a 3-MHz micropulse repetition rate with micropulse charges selectable from 2 pC to 3.2 nC by adjusting the UV laser intensity. The quantum efficiency of the Cs_2Te photocathode is 1-2 %, and the photoelectrons exit the gun at up to 5 MeV energy. After the rf gun there is a diagnostics station that includes an insertable profile screen, two rf BPMs, and an insertable Faraday cup to characterize the 4-5 MeV beam. The beam is captured in an L-band superconducting rf accelerator structure with 15-22 MV/m nominal gradient. This is followed by a beamline with a suite of diagnostics including rf BPMs, two toroids, a wall current monitor, a series of loss monitors, and 7 beam-profiling stations. Three of these are configured in the chicane, the bunch longitudinal profiling station, and in the focal plane of the electron spectrometer. A schematic of the beamline is shown in Fig. 1. There is a chicane bypass line which we employed in initial commissioning. Since the bunch length monitor is after the chicane, using the bypass line we can measure the bunch lengths without chicane based compression and then with chicane compression once it is commissioned.

The Bunch Length Monitors

The bunch length monitor architecture was intended to provide a central collection point for the various source points whose radiation is transported into the MPI box. As indicated in Fig. 2, the coherent and optical synchrotron radiation ((CSR) and (OSR), respectively) sources from two chicane dipoles, OTR, CTR, and CDR from the X121 station, and the OTR from the spectrometer focal plane are also available to the system as described previously [4]. However, for this initial commissioning period with no compression, we emphasize the streak camera implementation. The streak camera was located outside of the tunnel in a small enclosed optical table. This involves an ~15 m transport with eight mirrors. The mirror system is adjusted using alignment laser beams.

Readout from the streak camera is performed using a Prosilica 1.3 Mpixel GiG-E vision camera with a 2/3" CCD and with fiberoptic coupling from the tube phosphor. We had previously used both the online Java-based ImageTool and the offline MATLAB-based ImageTool processing programs [5,6] in the commissioning of the laser lab streak camera system. Initial measurements of the UV component indicated the bunch length Gaussian fit sigma to be ~ 4 ps, Unless noted otherwise, the streak camera's synchroscan unit was phase locked to the master oscillator, which operationally provides the rf sync for the linac, rf gun, and UV drive laser. We provided a description of the commissioning of the streak camera system and image acquisition tools and the application to the drive laser previously [7].

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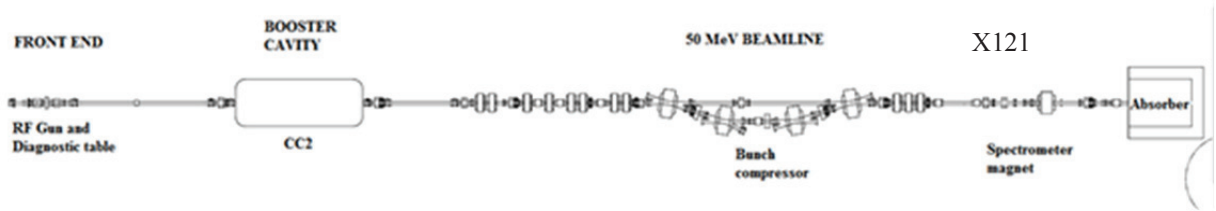

Figure 1: Schematic of the ASTA beamline showing the rf gun, booster cavity, chicane area, the X121 station, and the low energy spectrometer.

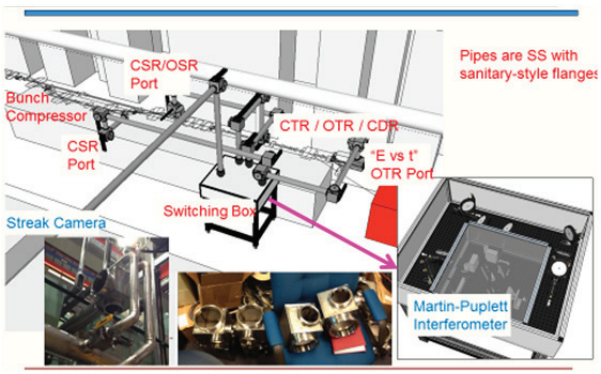

Figure 2: Schematic layout of the multiple sources assessable for bunch length information. Due to the elongated bunch, we will initially look for OTR signals from the X121 Al-Si screen.

For the linac streak camera we have used a fiber optically coupled Prosilica 1.3 Mpix CCD.

The Hamamatsu C5680 Streak Camera System

Commissioning of the streak camera system was facilitated through a new suite of controls centered around ACNET, the Fermilab accelerator controls network. This suite included operational drivers to control and monitor the streak camera as well as Synoptic displays to facilitate interface with the driver and Java-based ImageTool programs to retrieve images from the readout camera. This commissioning period allowed for a number of improvements to be made to all aspects of interfacing with the streak camera, both in terms of front-end and back-end software, and hardware.

The streak camera consists of a Hamamatsu C5680 mainframe with S20 PC streak tube and can accommodate a vertical sweep plugin unit and either a horizontal sweep unit or blanking unit. For the laser room, the UV-visible input optics allowed the assessment of the 263-nm component as well as the amplified green component or IR components converted to green by a doubling crystal. For the linac case with broadband OTR emission, we used the all-mirror A6856 input optics from Hamamatsu as shown in Fig. 3. We started the studies with the M5675 synchroscan unit with its resonant circuit tuned to 81.25 MHz and the horizontal sweep unit. The low level rf is amplified in the camera to provide a sine wave deflection voltage for the vertical plates that results in low jitter (~1ps) of the streak camera images and allows synchronous summing of a pulse train. The temporal resolution is about 1.5 ps FWHM, or 0.6 ps sigma, for NIR photons at 800 nm. When combined with the C6878 phase locked loop (PLL) delay box we can track phase effects at the ps level over several minutes (and even hours as long as the unit phase balance is stable) and within the macropulse to about 200 fs. As a point of comparison, the M5676 vertical fast sweep unit has about 20-ps internal trigger jitter in addition to the nominal 100-ps trigger jitter of the alternative DG535 delay units. This would mean the streak image would jitter in and out of the frame when running on the fastest sweep range with a full scale range of about 150 ps, illustrating the critical advantage of the synchroscan mode. As noted, we have replaced the Hamamatsu Peltier-cooled firewire CCD readout camera with a Prosilica 1.3-Mpix Gig-E vision digital CCD which is thus compatible with the video acquisition [5,6] specified for all of the RadiaBeam beamline imaging stations. The commissioning of this readout camera as well as the image analysis tools was one of the goals of the tests.

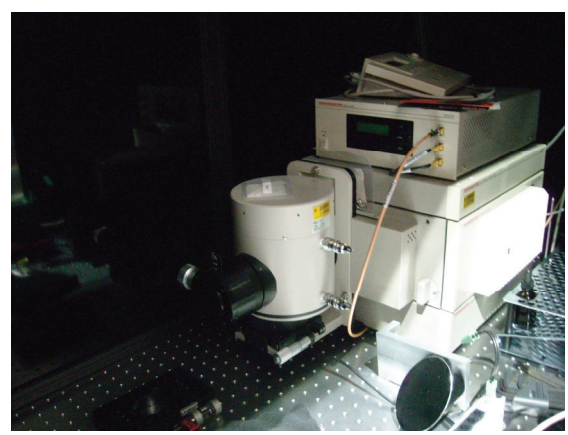

Figure 3: Photograph of the C5680 streak camera with mirror optics input in the optical enclosure. The OTR is transported to the streak camera from the switching box seen in Fig. 2.

There is a fundamental reduced sensitivity issue of the Prosilica camera compared to the cooled CCD camera that require image averaging techniques when viewing OTR. The concept of the streak tube's using the 81.25 MHz rf from the master oscillator to generate the vertical deflection voltages with the phase-locked delay box was critical. This combination enabled a new series of experiments at Fermilab's A0 Photoinjector [8] and will also apply at ASTA. A second set of deflection plates provides the orthogonal deflection for the slower time axis in the 100-ns to 10-ms regime.

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EXPERIMENTAL RESULTS

Commissioning of the linac only started recently in March 2015 with nominal measured energy of 20.3 MeV and charge of 250 pC per micropulse. The initial commissioning of the streak camera was done several weeks later. We show initial results in the following.

First Beam in the Low Energy Absorber

On March 27, 2015 we achieved our first beam to the low energy absorber. On this first day we actually used the OTR screen and the CCD camera optics. In later days we used the YAG:Ce screen. The initial OTR image for a pulse train of 60 micropulses is shown in Fig. 4. The energy is displayed on the horizontal axis. In the future we would add a transport line as indicated in Fig. 2 to assess viability of E-t information via the streak camera. The projected profiles for x (below the image) and y (right of image) are also shown in Fig. 4 with a single Gaussian curve fit (red).

First OTR Streak Images with 20 MeV Beam

On April 23, 2015 we obtained our first streak images. We first transported the beam to the X121 station and used the three upstream quadrupoles (Q118, Q119, and Q120) to produce a small spot with Gaussian fit sigmas of about 90 µm x 260 µm. We used the horizontal and vertical (H/V) 120 dipole correctors near Q120 roughly 1 m upstream of X121 to setup an e-beam rastering scan range at the X121 screen location. This YAG:Ce screen with its mirror

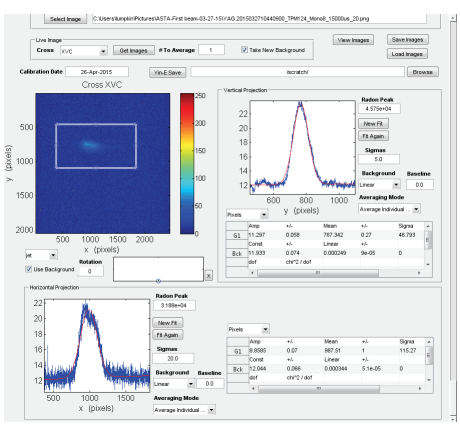

Figure 4: One of the first OTR beam images at ASTA of 20 MeV beam following the spectrometer magnet obtained on March 27, 2015.

at 45 degrees to the beam direction directs light out beam right through the optical transport to a Prosilica 5 Mpix GiG-E CCD. We then inserted the OTR screen with its mirror reflecting light beam left into the transport line of the streak camera. We opened the entrance slit to 100 µm to allow for enough signal in our first setup. The initial slit image was found to have a sigma of 8.9 pixels (3.3 ps term equivalent) in focus mode. In the image of Fig. 5, the vertical display axis is time, and the horizontal display axis is the y spatial axis. The projected time profile is shown at the right of the image. The case with 250 pC micropulse charge shown has a bunch length of σ=10.3 ps with the rf cavity phased for minimum energy spread. With a change in optical focus of the OTR at the slit, we recently closed the slit to 30 µm with a corresponding slit image size of 3.2 pixels to obtain 1.2-ps resolution operations with reasonable statistics. We tracked the electron bunch length elongation from ~8 to 14 ps with charges of 100 to 1000 pC, respectively.

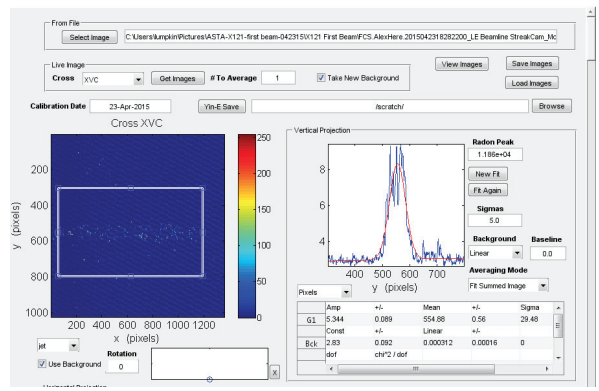

Figure 5: Synchroscan OTR streak image using the fastest streak range 1 (R1 cal.: 0.37 ps/pix as calibrated against a Colby delay box) showing the bunch length on the vertical image axis of 29 pixels (~10 ps (σ)).

SUMMARY

In summary, we have reported our first commissioning results and bunch length measurements of the ASTA linac streak camera using the optical transport from the tunnel, mirror input optics, and new Prosilica Gig-E readout camera with fiber optic coupling. We expect the chicane will be commissioned in the coming months so our studies with the compressed electron beam may ensue.

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