INITIAL COMMISSIONING OF A DUAL-SWEEP STREAK CAMERA ON THE A0 PHOTOINJECTOR

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Abstract
Characterization of the micropulse bunch lengths and phase stability of the drive laser and the electron beam continue to be of interest at the Fermilab A0 Photoinjector facility. Upgrades to the existing Hamamatsu C5680 streak camera were identified, and initially a synchroscan unit tuned to 81.25 MHz was installed to provide a method for synchronous summing of the micropulses from the drive laser and the optical transition radiation (OTR) generated by the e-beam. A phase-locked delay box was also added to the system to provide phase stability of ~1 ps over tens of minutes. Initial e-beam measurements identified a significant space-charge effect on the bunch length and other bunch length measurements supported the A0 emittance exchange experiments. Recent measurements with a re-optimized transverse emittance allowed the reduction of the micropulse number from 50 to 10 with 1 nC each to obtain a useful streak image. Installation of the recently procured dual-sweep module in the mainframe has now been done. Initial commissioning results and sub-macropulse display of the electron beam via OTR will be presented.

INTRODUCTION
The opportunity for a new series of streak camera experiments at the Fermilab A0 photoinjector was recognized in the last year. The first enabling upgrade was adding the synchroscan option to the existing C5680 Hamamatsu streak camera mainframe. By locking this module to the 81.25 MHz subharmonic of the rf system, the synchronous summing of micropulses could be done with trigger jitter of <1.5 ps (FWHM) for both the UV drive laser component at 244 nm and the e-beam via optical transition radiation (OTR) measurements [1,2]. The synchronous summing of the low OTR signal from the UV laser bunch length, a series of e-beam experiments were performed with the fast single-sweep module of the Hamamatsu C5680 streak camera with an inherent shot-to-shot trigger jitter of 10 to 20 ps. Such jitter precluded synchronous summing of the short micropulses. We have upgraded the camera by acquiring the M5676 synchroscan module tuned to 81.25 MHz with a trigger jitter of less than 1.5 ps (FWHM) and the C6878 phase-locked delay unit which stabilizes the camera phase over 10s of minutes. Due to the low, electron-beam energies and OTR signals, we typically synchronously summed over 50 micropulses with 1 nC per micropulse. The initial sampling station was chosen at Cross #9, and an optical transport system using flat mirrors and a parabolic mirror brought the light to the streak camera as indicated in Fig. 1. A short focal length quartz lens was used to focus the beam image more tightly onto the streak camera entrance slit. The quartz-based UV-Vis input optics barrel transferred the slit image to the Hamamatsu C5680 streak camera’s photocathode. Alternatively, the 4-dipoles of the emittance exchange (EEX) line could be powered and experiments done at an OTR station, Cross #24, after the fourth dipole. A second optical transport line brings the OTR to the streak camera entrance slit. The OTR converter is

EXPERIMENTAL BACKGROUND
The tests were performed at the Fermilab A0 photoinjector facility which includes an L-band photocathode (PC) rf gun and a 9-cell SC rf accelerating structure which combine to generate up to 16-MeV electron beams [4]. The drive laser operates at 81.25 MHz although the micropulse structure is usually divided down to 9 MHz. Previous bunch length measurements of the drive laser and e-beam [2] were done with the fast single-sweep module of the Hamamatsu C5680 streak camera with an inherent shot-to-shot trigger jitter of 10 to 20 ps. Such jitter precluded synchronous summing of the short micropulses. We have upgraded the camera by acquiring the M5676 synchroscan module tuned to 81.25 MHz with a trigger jitter of less than 1.5 ps (FWHM) and the C6878 phase-locked delay unit which stabilizes the camera phase over 10s of minutes. Due to the low, electron-beam energies and OTR signals, we typically synchronously summed over 50 micropulses with 1 nC per micropulse. The initial sampling station was chosen at Cross #9, and an optical transport system using flat mirrors and a parabolic mirror brought the light to the streak camera as indicated in Fig. 1. A short focal length quartz lens was used to focus the beam image more tightly onto the streak camera entrance slit. The quartz-based UV-Vis input optics barrel transferred the slit image to the Hamamatsu C5680 streak camera’s photocathode. Alternatively, the 4-dipoles of the emittance exchange (EEX) line could be powered and experiments done at an OTR station, Cross #24, after the fourth dipole. A second optical transport line brings the OTR to the streak camera. In the EEX line the bunch compression effects were observed, and the shorter bunches were used to help delineate the chromatic temporal dispersion effects for various band pass, long pass, and short pass filters. The OTR converter is
an Al-coated optics mirror that is 1.5 mm thick with a Zerodur substrate, and is mounted with its surface normal at 45 degrees to the beam direction on a stepper assembly. The assembly provides vertical positioning with an option for a YAG:Ce scintillator crystal position. We still suspect the larger beam sizes may have resulted in incomplete signal collection over angle space. A two-position actuator and a 4-position translation stage were used in the optical path in front of the camera to select band pass filters. The OTR streak readout camera images were recorded with a PCI-compatible video digitizer for both online and offline image analyses. The charge was monitored by an upstream current monitor.

**RESOLUTION AND BANDWIDTH EFFECTS**

The calibration of the two fastest streak ranges, R1 and R2, using a laser pulse stacker was described previously [3]. Here we summarize that the calibration factors are 1.55 ps/ch for R2 and 0.32 ps/ch for R1. With a limiting vertical spot size of about 4.7 ch (FWHM) in focus mode, the limiting tube resolution is about 1.5 ps FWHM. However, one of the practical issues we addressed was the chromatic temporal dispersion that occurred for the broadband OTR light as it was transported through the transmissive components of the optical transport line. Since the input optics barrel of the streak camera was actually UV transmitting, it consisted of quartz optical components. This material has less variation of index of refraction with wavelength than flint glass or other materials used in the other standard Hamamatsu input optics, but still results in a measurable effect that limits effective temporal resolution with broadband light. Our effect was shown to be smaller than the SSRL setup of 0.2 ps/nm reported at PAC07 [5]. The basic concept is expressed by the simple relationship for the transit-time change, 
\[ \Delta t = \frac{L (v_{g2} - v_{g1})}{v_{g1} x v_{g2}}, \]
due to the difference in group velocities \( v_{g1} \) and \( v_{g2} \) for two wavelengths through a characteristic material thickness, \( L \) [6].

This effect is represented in Fig. 2 where a 3-ps FWHM actual pulse is shown as arriving at different times for different wavelengths with a 4-ps shift across the bandwidth of the measurement. The resulting superposition of these Gaussian profiles can be fit to a single Gaussian of 4.21 ps (FWHM). In the actual MATLAB model, a series of over 1000 Gaussians was used. In our case the temporal shift was 8 to 9 ps within the 550-nm shortpass filter bandwidth and caused an effective limiting resolution term of about 4.4 pixels (FWHM) for range 2 in quadrature with the static spread function of 4.7 pixels.

![Figure 2](image)

**STREAK CAMERA OTR RESULTS**

The experiments were usually initiated by verifying the OTR-deduced spot sizes and centering of the beam on the screen centerline and the downstream rf BPM...
coordinates. We would optimize the signal transported through the entrance slit of the streak camera while in Focus mode. We then switched to either R2 or R1, set the delay for viewing the streak images, and phase locked the delay box. The initial investigations in the straight ahead line were reported elsewhere [3].

The next series of investigations was done in the other beam line that is setup for emittance exchange experiments [7]. A liquid-N\textsubscript{2}-cooled, 5-cell TM\textsubscript{110} rf deflector cavity is positioned between two magnet transport doglegs. Additionally, the trajectory change with beam energy can be studied via the transit time changes through the doglegs as shown in Fig. 3. The phase-locked streak images allow the change in image time position to be used to track the arrival time change. One can see that a ±1% change in momentum causes an about ±6 ps change, respectively, in transit time through the bends. These data were used to evaluate one of the transport matrix elements of the emittance exchange line.

Figure 3: A plot of the change in transit time through the doglegs for different 9-cell rf amplitudes, and hence momentum changes, Delta P.

Critical measurements on one aspect of the x-z emittance exchange experiments were performed this year [7]. We observed the very clear reduction of the bunch length as a result of the exchange seen in Fig. 5. The 5-cell cavity-off data are clearly 4-5 times longer than the cavity-on data. The shortest bunches are close to the detection limit with a value of 1.4 ±0.9 ps (FWHM) when we use the 550-nm LP filter.

Figure 4: Direct measurement of the x-z emittance exchange and the bunch-length reduction with the 5-cell cavity power on versus cavity power off.

The dual-sweep measurements are in their initial stages. With the improved emittance, smaller beam sizes could be obtained and these resulted in improved photon statistics for the streak images. OTR from 10 bunches at X9 was first measured with synchroscan only as shown in Fig. 5 (left). Then the 10-\mu s range was selected for horizontal sweep. Due to the internal trigger delay of 5 µs, we see the last 5 of the 10 micropulses in the image at the right.

Figure 5: Examples of synchroscan image of 10 micropulses (L) and the dual-sweep image showing 5 of the individual micropulses across the horizontal axis (R). The vertical deflection range is R2 so it spans ~750 ps.

SUMMARY

In summary, we have extended the investigations on streak camera imaging of the ~15-MeV electron beam in the transport lines of the A0 photoinjector using OTR as the conversion mechanism. The enabling steps for these measurements were the installations of the synchroscan module in the streak camera mainframe, the new phase-locked delay box, and the horizontal sweep unit. These allowed synchronous summing of micropulses with much lower jitter than the single sweep unit and with the phase stability locked over 10s of minutes. In addition sub-macropulse effects of the UV laser and the e-beam can now be evaluated with the dual-sweep mode.

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