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 15-MeV electron beam micropulses allowed the needed bandpass filters to be utilized to reduce the chromatic temporal dispersion effects inherent to the broadband OTR source and the transmissive optics components. In addition, the C6768 delay module with phase feedback was also acquired, and this stabilized the streak camera sweep relative to the master oscillator so that camera phase drift was much reduced to the ps level over tens of minutes. This second enabling upgrade allowed a series of experiments to be done on the bandwidth effects and transit-time effects in the respective transport lines[3].

The third enabling upgrade involves our installation and initial commissioning of the horizontal deflection unit which allows dual-sweep streak camera operations. In this case we want to assess the phase jitter and/or slew at the ps level during the macropulse of the drive laser and the electron beam. In synchroscan mode we have synchronously summed over all the micropulses and the jitter and slew effects are included. After characterizing the UV laser bunch length, a series of e-beam experiments on the A0 beamlines was performed [3]. We report measurements of the beam transit time in a double-dogleg transport line as a function of the upstream 9-cell accelerator rf amplitude and the effects of emittance exchange in the x-z phase spaces. We then show our initial dual-sweep streak results on the e-beam.

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 pulses. 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

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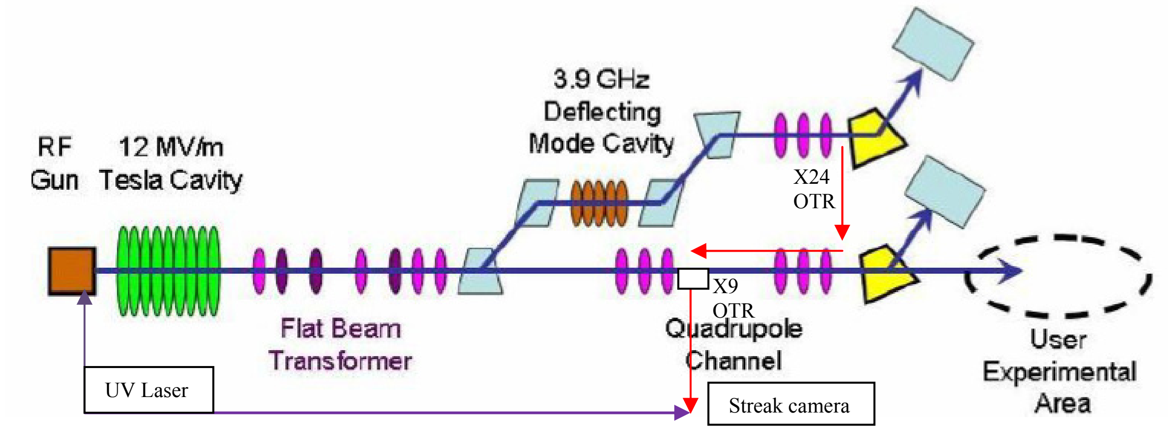

Figure 1: A schematic of the A0 photoinjector test area showing the PC rf gun, UV laser, 9-cell Tesla cavity, the OTR stations, the streak camera, and the second beamline when the two sets of dogleg dipoles are powered.

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 0.32ps/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, $\Delta t = L\,(v_{g2}-v_{g1})/(v_{g1} \times v_{g2})$, 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.

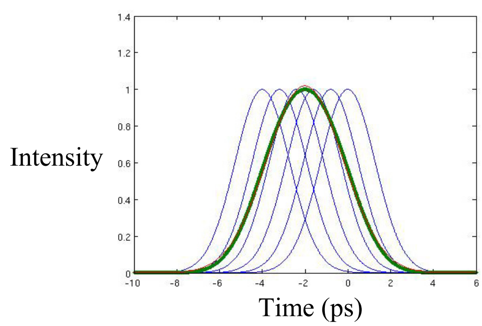

Figure 2: A simple representation of the group velocity dispersion effect on the streak image for a 3-ps FWHM initial pulse and a 4-ps temporal shift in the bandwidth used. The blue curves represent the series of Gaussians time shifted with wavelength. The resultant streak image profile has a 4.21 ps (FWHM) size (green curve).

We then can calculate the actual pulse length by subtracting from the total observed pulse width in pixels the contributing terms of static spread function, bandwidth, and trigger jitter. Since the jitter term appears to be small compared to our bunch lengths, we have absorbed it into the actual bunch length term for the time being. Then for range 2 and range 1 we would have with the 550 nm shortpass filter, respectively:

$$\delta t(FWHM) = \sqrt{Pixel^2 - 4.7^2 - 4.4^2} \times 1.55\,ps/pixel$$

$$\delta t(FWHM) = \sqrt{Pixel^2 - 4.7^2 - 22^2} \times 0.32\,ps/pixel$$

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_2-cooled, 5-cell TM_{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.

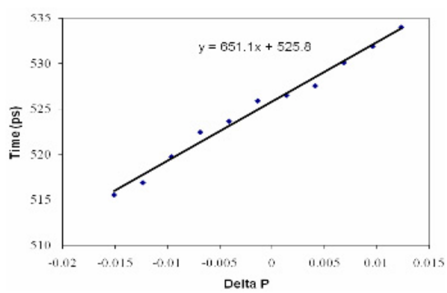

Figure 3: A plot of the change in transit time through the doglegs for different 9-cell rf amplitudes, and hence momentum changes, Delta P.

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.

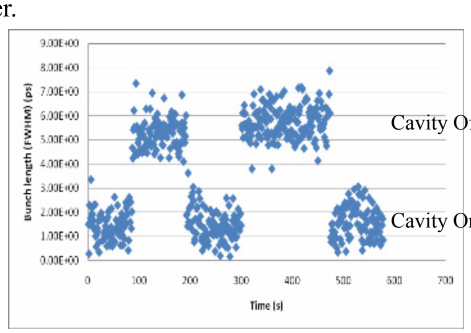

Figure 4: Direct measurement of the x-z emittance exchange and the bunch-length reduction with the 5-cell cavity power on versus cavity power off.

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-µs 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.

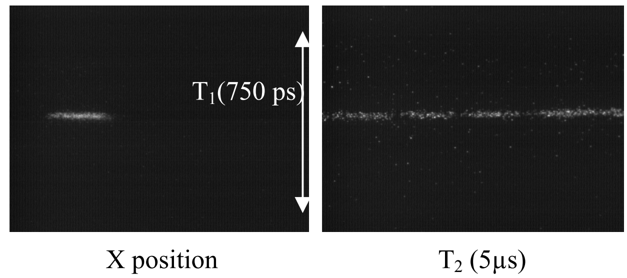

Figure 5: Examples of synchroscan image of 10 micropulses (L) and the dual-sweep image showing 5 of the individual micropulses across the horizontal axis (R). The vertical deflection range is R2 so it spans ~750 ps.

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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