LASER TIMING JITTER MEASUREMENTS USING A DUAL-SWEEP STREAK CAMERA AT THE A0 PHOTOINJECTOR*

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Abstract

Excellent phase stability of the drive laser is a critical performance specification of photoinjectors such as Fermilab's A0 photoinjector (A0PI). Previous efforts based on the measurement of the power spectrum of the signal of a fast photodiode illuminated by the mode locked infrared laser pulse component indicated a phase jitter of less than 1.4 ps (technique limited). A recently procured dual-sweep plugin unit and existing Hamamatsu C5680 streak camera were used to study the phase stability of the UV laser pulse component. Initial measurements with the synchroscan vertical sweep unit locked to 81.25 MHz showed that the phase slew through the micropulse train and the phase jitter micropulse to micropulse were two key aspects that could be evaluated. The phase slew was much less than 100 fs per micropulse, and the total phase jitter (camera, trigger, and laser) was approximately 300 fs RMS for measurements of 50-micropulse trains. Data on the macropulse phase stability were also obtained. A possible upgrade to achieve better phase stability will be also discussed.

INTRODUCTION

Photoinjectors are widely used in modern accelerators due to their high brightness and low emittance beam. This technology is also one of the candiates as the electron source for the future international linear collider (ILC). The A0 photoinjector consists of a 1.3 GHz copper RF gun and a TESLA type RF cavity. The energy of the beam is typically arround 16 MeV. [1] The performance of this photoinjector is directorly related of the performance of the driven laser system. For example the uniformity of the laser spot will influence the emittance of electron beam.

To achieve a high quality beam for advanced accelerator R&D it is important to maintain a stable laser in terms of both intensity and timing. Previous efforts to measure the laser timing jitter by examining the power spectrum of the seed laser at the 12th harmonic resolves a sub 200 fs jitter. However, when we try to measure the phase of a cavity impulsively excited by the the signal of a fast photodiode illuminated by the pulsed laser shot (jitter between micropulse train), one only measures an laser pulse jitter of 1.4 ps due to the resolution of our data acquisition system.[3]

In this paper we will report the effort to study the phase stability of the UV laser pulse inside both micropulse train and macropulse train using a new procured dual sweep plugin unit and existing Hammamatsu C5680 streak camera unit. We will first describe the experiment and some calibration work. Then we will report the reasults with UV laser pulse in dual sweep mode. This will reveal the jitter among the microbunch inside the pulse train. Finally we will also discuss the jitter between individual macropulse train and possible cause.

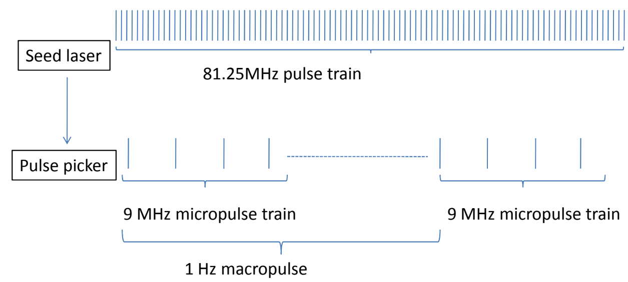

Figure 1: Schematic of the micropulse train and macropulse train at A0.

EXPERIMENTS

Set up and initial calibration

The A0 Laser System consists of a seed laser, a multi pass amplifier and a 2 pass amplifying structure and two sets of doubling crystals. The laser begins as a continuous train having 5.5 nJ per FWHM 5 ps long infrared (1054 nm) laser pulses at 81.25 MHz. (GE-100 from Time bandwidth) After passing through a pulse picker 81.25MHz train will be shaped as a 9 MHz micropulse train with a pulse number varied from 1-1000. The repetition rates of the micropulse train is 1Hz. The pulse structure is shown as fig 1. The macropulse pulse train will then go through the multi pass amplifier and the 2 pass amplifing structure. Both macropulse train and mircropulse train is sketched in figure 1. The amplified infrared pulse then passes through two sets of doubling crystals to become first green, then ultraviolet (UV) pulse. More detail of the driven laser system at A0 can be found in Ref. [2].

After being converted from IR to UV inside the laser room, the UV laser is transfered to the photo injector tunnel using a UV imaging system to the photocathode, which is located 20 m away from the UV mask in laser room. After hitting the vacuum window more than 95% beam is transmitted to hit the photo cathode. the other 5% is reflected back and imaged it to a virtual cathode. In order to monitor the laser bunch length in real time without interuption of

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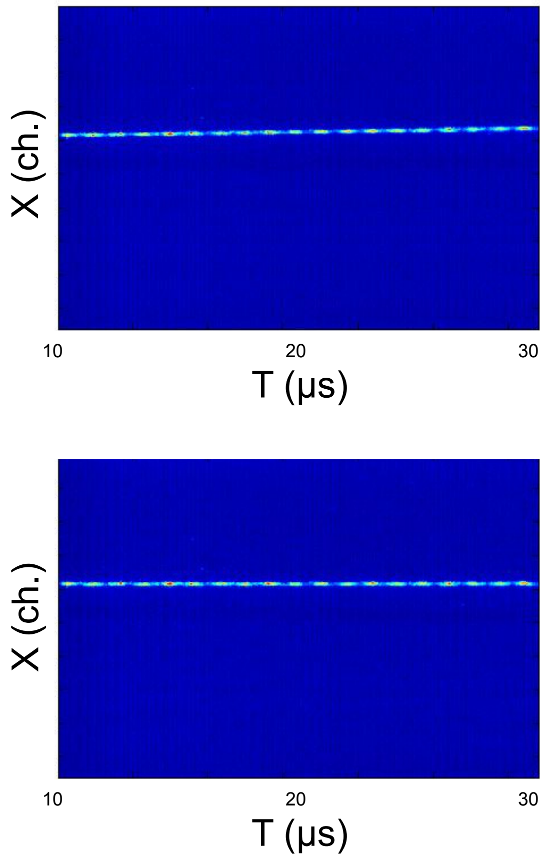

Figure 2: Top is the original focus mode image from the streak camera with 20 pulses. Bottom is the corrected version using matlab.

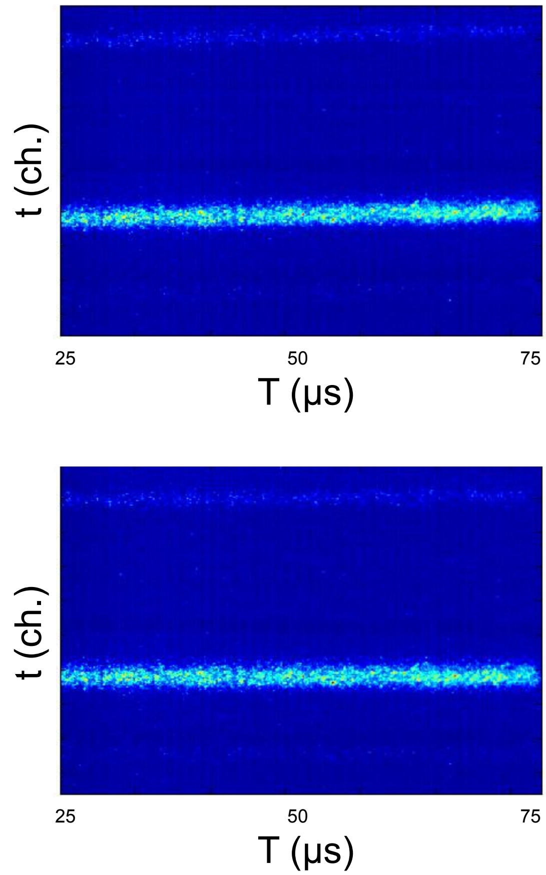

Figure 3: Top is the the original streak mode picture from streak camera with 50 pulses. Bottom is the corrected version.

the photoinjector run we redirected the beam reflected back from the vacuum window and imaged onto the entrance of the streak camera, which was also located inside the tunnel. The operation and calibration procedure of the streak camera unit without the dual sweep unit is described in [4]. For our jitter studies the fastest range is chosen, which has a calibration factor of 0.32 ps/pixel.

In order to measure the jitter accurately initial calibration is done using UV laser at the fous mode with the dual sweep unit on. The original focus image is shown at the top of figure 2. The beam shows a very obvious slope. Because we are operating under focus mode there should be no arrival time difference between each of the micropulses. This can be attributed to the slight mis-rotation of the fiber coupled CCD unit. However this will contribute to our phase jitter or phase slew calculation once we operate the streak camera under streak mode. To eliminate this effect we develop a algorithum to process the image using matlab. The processd image is shown in the bottom of figure 2. And the same algorithum will be applied to streak mode measurement later on. It's worth to note that we also can extract the vertical position of each bunch from the processed image. The RMS of the position variation is on the order of 0.15 pixel from 25 images in this case, which will correspond to around 50 fs in time resolution. That sets the temporal sensitivity for our jitter measurement using this method.

Experiment data and discussions

The streak mode picture for 50 bunches is shown on the top of figure 3. On the picture there's actually 2 streak images seen. The intense one is from the main UV pulse and the weak one is from the unwanted secondary pulse during the test. The main reason for the unwanted secondary pulse is that the rising and falling time of our pulse picker unit is close to the spacing between the pulse from the seed oscillator. Just as seen from the focus image , the whole streak image is also tilted in the same way due to the camera as shown . We applied the same algorithum to correct the image. The correct image is shown at the bottom of the figure 3.

In order to calculate the jitter among the 50 microbunches on the screen we divided the screen into 50 vertical slices. For each vertical slice we do the projec-

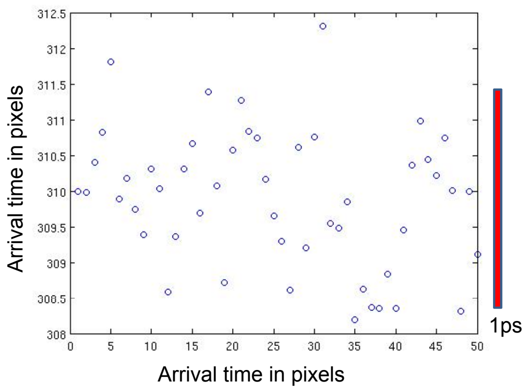

Figure 4: Example of the distribution of the arrival time of 50 micropulses in figure 3.

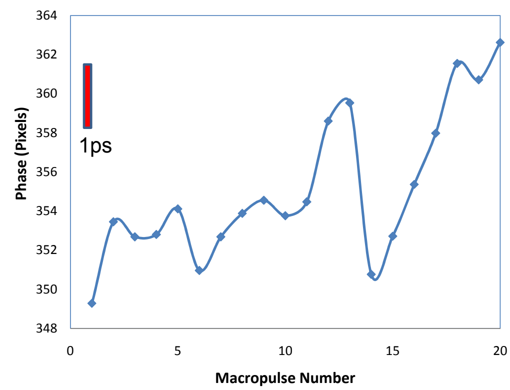

Figure 5: Example of the distribution of the arrival time of 20 macropulses.

tion and fit with a Gaussian function to get the centroid position in pixels. In Figure 4 an example of the distribution of the arrival time of the 50 micropulses in figure 3 is shown. There's very little phase slew seen for this 50 bunches. The root mean square (rms) value for this distribution is 0.93$\pm$0.05 pixels, which corresponds to 293$\pm$16 fs. We know that our seed laser contributes a jitter of 200 fs from the manufactory data. The other part is coming from the streak camera. The jitter from the unit is in the order of 200 fs as well. Because these two effects are independent they can be added in quadrature, for a total of 280 fs. This means that very limited timing jitter is caused by the infrared amplifing chain and transport at the microbunch level, i.e., within several μseconds.

As for the macropulses we took the data for a continuous 20 shot. In figure 5 the average arrival time is plotted. We can see the data is noiser then the microbunch data. The rms jitter value is 3.84 pixels, i.e., 1.23 ps. Most of these is contributed by the fact the the macropulse is happened in a much longer time scale (1 second) than the micropulse (1 μsecond). At this stage we attribute the most of the timing jitter we observe in macropulse to the infra-red amplifying chain. For example we used flash lamp in our amplifying chain. The firing of the flash lamp is controlled by 1Hz trigger. Both the amplitude jitter and timg jitter of the flash lamp could contribute to the macrobunch jitter. We believe that this portion of the jitter can be corrected when we switch from flash lamp pumped amplifying structure to diode laserd pumped amplifying structure at the next upgrade plan. Another possible source of the jitter may be the mechanical vibrations of the tranport system from laser lab to photocathode gun.

SUMMARY

In summary a recently procured dual-sweep plugin unit and existing Hamamatsu C5680 streak camera were used to study the phase stability of the UV laser pulse component. The phase jitter between the micropulses is on the order of 300 fs while the phase jitter between the macropulse is on the order of 1 ps. There's very little phase slew within the microbunch train. The measured phase jitter among the micropulse is mainly caused by the seed laser and streak camera phase lock resolution. The jitter among the macropulse is mainly cause by the amplifying chain and the transport system. Further investigation are planned.

ACKNOWLEDGEMENT

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REFERENCES

[1] `http://www-a0.fnal.gov`

[2] J. Li, R. Tikhoplav and A. C. Mellisinos, "Performance of the upgraded laser system for the Fermilab-NIU photoinjector", Nucl. Instrum. Meth., A564:57-65, (2006)

[3] Justin Kien Keung, Jinhao Ruan and Sergei Nergaitsev, "Laser Timing Jitter Measurements at the Fermilab A0 Photoinjector", LINAC08

[4] A.H. Lumpkin and J. Ruan, "Initial Synchroscan Streak Camera Imaging at the A0 Photoinjector", BIW08,