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EOM-BASED BUNCH ARRIVAL MONITOR DEVELOPMENT AT THE ARGONNE WAKEFIELD ACCELERATOR FACILITY*

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Abstract

A new bunch arrival monitor (BAM) prototype instrument is developed under a collaboration between Advanced Photon Source (APS) and Argonne Wakefield Facility (AWA). This prototype instrument takes advantage of a commercial, electro-optic modulator (EOM) to measure the bunch arrival time through optical modulation. The klystron RF phase jitter and bunch arrival time jitter with respect to laser pulses were measured and the test results are presented.

INTRODUCTION

Argonne Wakefield Accelerator (AWA) facility is an accelerator test facility dedicated to research in beam physics and advanced acceleration concepts [1]. AWA uses a 1.3 GHz photocathode RF gun capable of generating high bunch charges from 1 pC up to 100 nC. Beam temporal diagnostic is important in such a facility. Currently, RF deflecting cavities operate as the main time-domain diagnostic.

At Argonne National Laboratory (ANL), we are developing a new diagnostic instrument, based on the electro-optical modulator (EOM). This is collaborative work between APS and AWA. This new instrument is non-destructive with high resolution. At AWA, it could be used for any RF or beam timing measurements and it could also be reconfigured for other electro-optical sampling research topics. Figure 1 shows

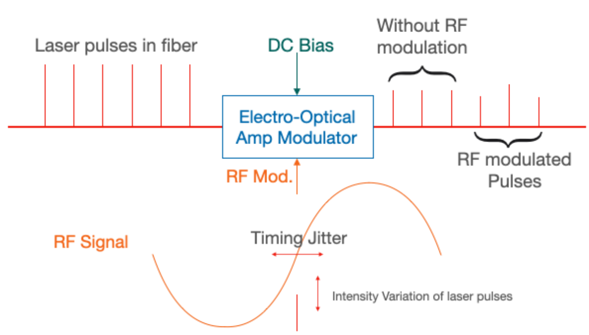

Figure 1: Basic principle of EOM-based BAM (from [2]).

the principle of EOM-based BAM. The EOM has two input ports [3], the DC bias, where the operating point is set by a DC control voltage, and the RF port, where the RF modulation is applied. In operating conditions, the DC bias voltage is set to make the laser output at about half of the maximum power, which corresponds to about 50% transmission. Then the laser pulses are linearly modulated by the RF input amplitude when they pass through the modulator. When laser pulses arrive around the zero crossing timing of the RF signal, the temporal variations of the RF signal are mapped to the intensity variation of the modulated laser pulses, as shown in Fig. 1.

SYSTEM DEVELOPMENT

Layout

The AWA laser system is based on a commercial mode-locked Titanium-Sapphire oscillator, which produces 785 nm, sub-100 fs laser pulses at 81.25 MHz. Figure 2 shows the system setup. A small portion of laser power is coupled into a single-mode PM fiber. A two-way splitter will split the laser power into two paths. About one-third of the laser is used for RF-laser synchronization. The rest is guided to the EOM. The half-wave plate can adjust the splitting ratio.

The RF modulation signal will go through a phase delay line and a broad-band RF Amp. Before the EOM, the signal phase is controlled by the stepper motor of the phase delay line. And a 50 GS/s scope is used as the Data Acquisition System (DAQ).

Software Development

To extract the pulse intensities and waveforms from the scope, customized data acquisition software was developed using C language. We included an interpolation process to estimate the envelope and peaks of the modulated laser pulses. And several EPIC PVs were added to support high-level control processes. The software could automatically detect and calculate all the laser pulse intensities within a 4 µs window. Given the repetition rate of laser pulses, the total number is 320.

Bias Control

As previously described, the DC bias voltage set the operation point. The RF-induced amplitude modulation is different as the operation point varies [4]. We need to keep the EOM operating at 50% transmission level, where the amplitude modulation is strong and the linear range is relatively large [5]. A bias control loop was developed to maintain the average reference laser intensity at the 50% transmission level by adjusting the DC bias voltage. Due to random thermal or mechanical perturbations, the laser power coupled to the fiber was drifting. A photodiode in the RF sync box was

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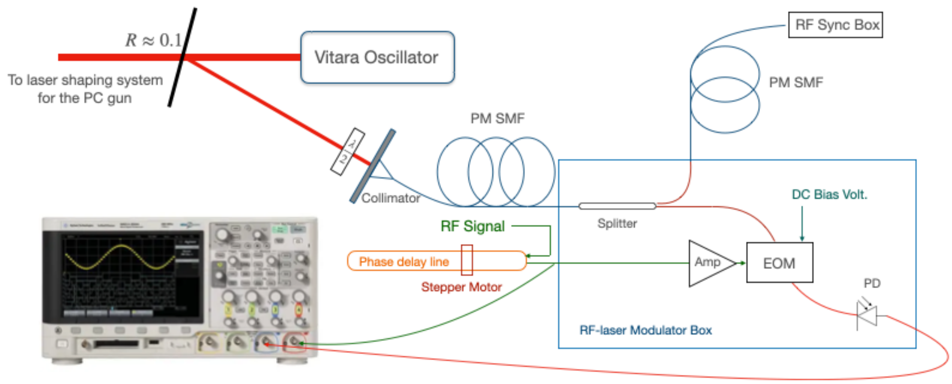

Figure 2: The prototype system setup in the AWA laser room.

used to monitor the drift and the set-point level was adjusted to compensate for this drift.

SYSTEM TEST

Klystron RF Phase Jitter

The phase jitter of the klystron, which powers the AWA drive photocathode gun, was measured with the prototype instrument. The klystron forward signal was coupled through a directional coupler. The RF pulse length was about 6 µs. Of the total 320 extracted laser pulses within the 4 µs window, we chose the first twenty signals as the reference signal for the bias loop and the last twenty pulses, which were about 2 µs after the RF pulse started, were chosen as the signal phase indicator.

Calibration is very critical to get accurate measurements. And the key is to find the RF zero-crossing, which is done by the phase sweeping by the stepper motor. The modulated and reference laser pulses were measured, averaged, and plotted, as shown in Fig. 3(a). By fitting the curve around the zero-crossing phase, we got the calibration coefficient $C = \frac{\delta V}{\delta T}$(mV/deg), based on which we mapped the modulated laser intensity variations to phase jitters. Note that the coefficient was only accurate within a range of around 10 degrees.

At the AWA facility, the RF and laser signals are phase-locked by a commercial synchronization box. The RF phase jitter with respect to the laser pulses was measured with this prototype instrument. As shown in Fig. 3(b), the blue curve was the measured phase jitter. And orange curve was the reference signal without modulation, which represented the system resolution. The bias control was kept active during the measurement. The measured phase RMS jitter was about 0.24 deg, which corresponded to around 0.5 picoseconds. The system resolution was about 0.035 deg, which was about 70 femtoseconds.

Bunch Arrival Time Jitter

The bunch arrival time jitter was measured by the prototype instrument. The AWA accelerator consists of several accelerators. We used the 70 MeV drive photoinjector and

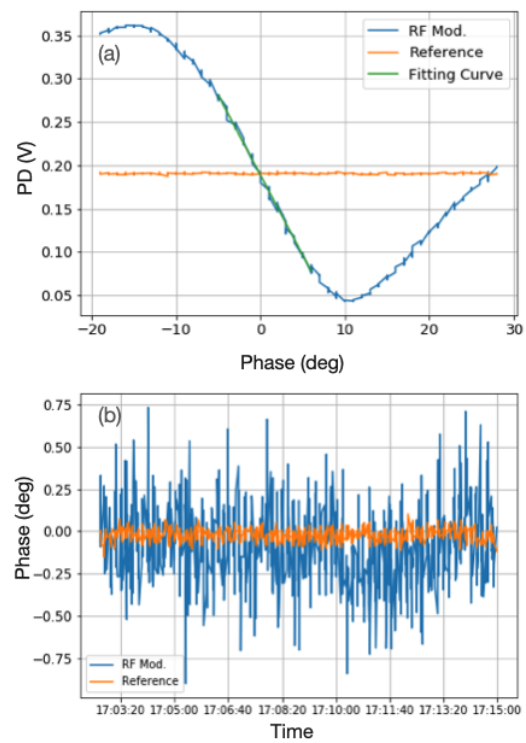

Figure 3: Klystron RF phase jitter measurement: (a) calibration curve and (b) phase jitter measurement.

we measured the bunch jitter by one button BPM, as shown in Fig. 4. The button BPM has four pickups. Two in the horizontal and two in the vertical plane. The signals of four pickups were combined and connected as the RF modulation signal. The beam energy was about 65 MeV during the test.

The bias control was on to maintain the 50% transmission level. Similarly to the previous klystron jitter measurement, the BPM signal phase also needs to be adjusted to make one laser pulse arrive at the EOM around the zero-crossing of the BPM signal, as shown in the Fig. 5 (a). The blue curve was the amplified BPM signal and the orange curve showed the laser pulse. This laser pulse intensity was measured and calibrated through a phase scan. Then we mapped the

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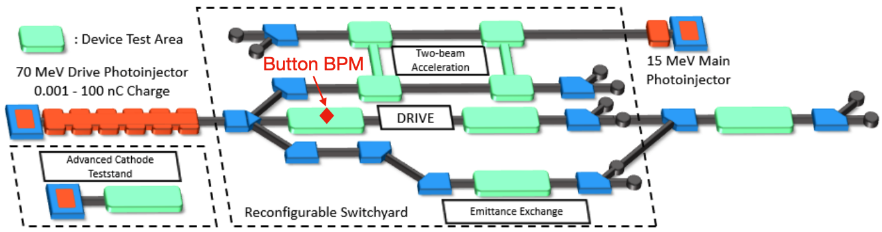

Figure 4: Overview of the AWA facility. The location of the BPM that we measured beam arrival jitter was marked.

intensity variation to the bunch jitter with respect to laser pulses. Figure 5(b) showed the beam jitter measurement at 10 nC.

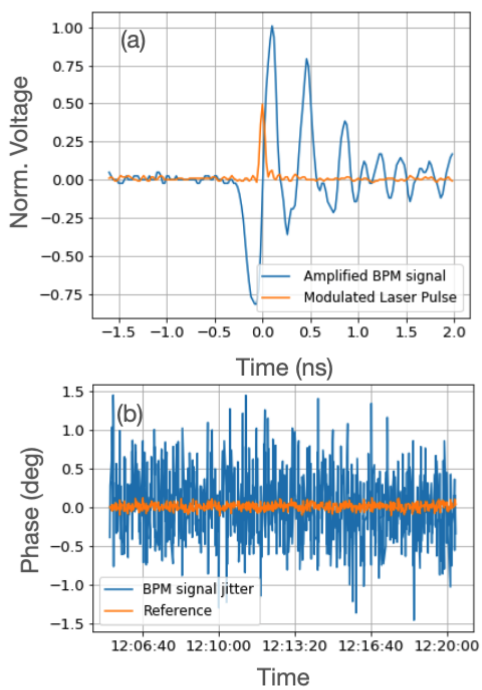

Figure 5: Bunch arrival jitter measurement: (a) One laser pulse arrived at the zero-crossing of the BPM signal. (b) 10 nC bunch jitter measurement.

Table 1: Calibration Coefficient and Measured Bunch Jitter with Different Bunch Charge

Charge	Cal. Coeff.	Beam RMS Jitter
1 nC	11.7 mV/deg	0.275 deg
3 nC	18.9 mV/deg	0.29 deg
5 nC	19.0 mV/deg	0.36 deg
10 nC	19.1 mV/deg	0.43 deg

During the test, we changed the bunch charge from 1 nC to about 10 nC. Table 1 summarizes the test result with different bunch charges. At each charge state, the instrument was calibrated and the bunch jitter was measured for about 15 min. A higher charge would generate a stronger signal in the BPM, which corresponded to a higher calibration coefficient. However, after reaching 3 nC, the RF amplifier was saturated due to the bandwidth limit and the coefficient didn't increase much as the charge increased. The measured bunch arrival jitter was about the same level as the klystron phase jitter at 1 nC. And higher charge would increase the bunch jitter by some amount. The measurement accuracy was mainly limited by the scope resolution. And we plan to change it to a dedicated ADC board in the next step.

CONCLUSION

A prototype Beam-Arrival Monitor has been developed at the AWA facility. The new instrument is based on a commercial EOM. The instrument offers a non-destructive timing measurement of RF signal by transferring the phase variation into laser intensity variation. Using the prototype instrument, we measured the klystron phase jitter and beam arrival time jitter with respect to laser pulses at the AWA facility. The prototype instrument has been integrated into the AWA laser-RF sync system and it can be reconfigured easily for various applications.

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