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PROTOTYPE OF THE BUNCH ARRIVAL TIME MONITOR FOR SHINE*

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Abstract

Bunch arrival time monitor (BAM) is an important tool to investigate the temporal characteristic of electron bunch in free electron lasers (FEL). Since the timing jitter of electron bunch will affect the FEL's stability and the resolution of time-resolved experiment at FELs, it is necessary to precisely measure the electron bunch's arrival time information to stabilize the electron bunch's timing jitter using beam-based feedback. The BAM based on electro-optic modulator (EOM) is currently being developing for Shanghai high-repetition-rate XFEL and Extreme light facility (SHINE). And the first BAM prototype has been installed on SXFEL for beam test. The beam test result shows that the estimated resolution of the prototype is about 27.5 fs rms.

INTRODUCTION

As a newly launched national big scientific infrastructure, Shanghai high-repetition-rate XFEL and Extreme light facility (SHINE) is now under construction. The main parameters of SHINE are listed in Table 1.

Table 1: Main Parameters of SHINE

Parameter	Value
Total length	3.1 km
Photo energy	0.4-25 keV
Beam energy	8 GeV
Repetition rate	1 MHz
Bunch length (FWHM)	1~100 fs

To investigate the longitudinal characteristic of the electron bunch, especially monitor the bunch arrival time. Two types of BAM, the RF-BAM based on phase cavity and RF phase detecting technology and the EO-BAM based on electro-optic modulation technology [1], are planned for SHINE and will be installed at different locations through the entire FEL facility. Because SHINE is under construction, BAMs designed for SHINE will firstly be tested at SXFEL. The RF-BAM has already been tested at SXFEL and obtained 45 fs arrival time resolution and 13 fs flight time resolution [2, 3], while efforts are ongoing to further improve the resolution. Meanwhile, the EO-BAM is still under development. This paper will focus on the development of the EO-BAM, therefore all BAMs mentioned in the followed context stand for EO-BAM. Figure 1 shows the schematic diagram of the first prototype of the BAM. The BAM consists of three parts, the beam pick-up, the BAM frond-end and back-end. The beam pick-up is located in tunnel to extract the transient RF signal generated by the driving electron bunch. The BAM frond-end also placed in tunnel is used to transform the shifting of RF signal's first zero-crossing, which stands for the arrival time of the electron bunch, into intensity variation of a reference optical pulse. The BAM back-end placed outside the tunnel is used to detect the amplitude of the optical pulse and derive the electron bunch arrival time information. Because we want to achieve the BAM's core function as soon as possible, the first prototype is a simplified version compared to the final version of the BAM, for example, there is only one electro-optic modulation (EOM) in the BAM front-end, and the controllers in BAM are not yet integrated to the EPICS. At the time of this writing, the first BAM prototype has already been installed on SXFEL for beam test. In this paper, we will introduce the development of the first BAM prototype and the preliminary beam test result.

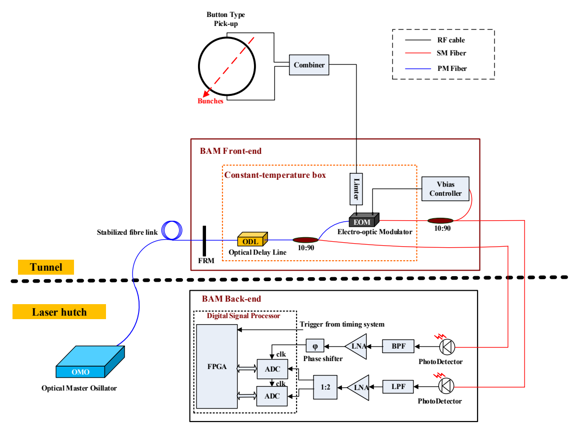

Figure 1: Schematic diagram of the first BAM protype.

THE DEVELOPMENT OF THE BAM PROTYPE

Button Type Pick-up

The slope at the first zero-crossing point of the pick-up signal is one of the key factors determine the resolution of BAM. To obtain a pick-up signal with steep slope under low bunch charge, a 35 GHz button type pick-up is being developing for BAM. The button type pickup consists of four radial arranged pick-up electrodes. Figure 2 shows the frequency-domain simulation result of the pick-up electrode, the simulated bandwidth is about 35 GHz. To measure the frequency response of the pick-up electrode, a special connector connects two electrodes together, while two RF cables connect the ports of the pick-up electrodes to the ports of the Network Analyzer. Figure 3 shows measured frequency response of the pick-up electrode. Ignoring the slow dropping in the frequency band range of 10 MHz to 45 GHz results from two RF cables, the bandwidth of the pick-up electrodes can achieve up to 40 GHz.

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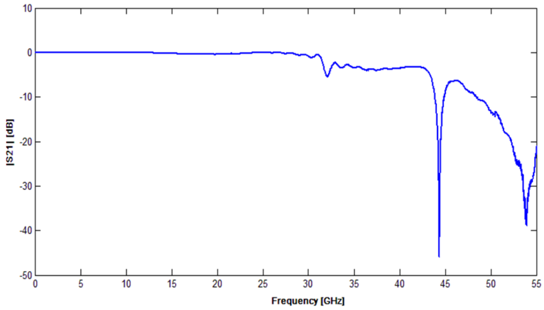

Figure 2: Frequency-domain simulation result of the pick-up electrode.

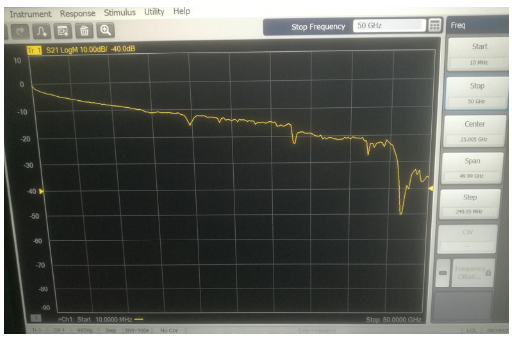

Figure 3: Measured frequency response of the pick-up electrode.

However, the welding of 35 GHz button type pick-up has not been completed. Therefore, we installed an 18 GHz button pick-up on SXFEL for the functional verification of the BAM prototype. Figure 4 shows the picture of the 18 GHz button type pick-up installed on SXFEL.

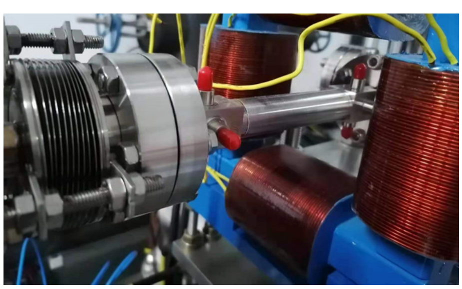

Figure 4: 18 GHz button type pick-up installed on SXFEL.

BAM Front-end

As show in Figure 1, the BAM front-end is all PM-fibre structure. And all the temperature-sensitive optical components, including the optical delay line, fibre splitter and EOM, are housed in a constant-temperature box. The box is made of aluminium and it's wrapped up with heat preservation material. We use thermal electronic cooler and the temperature controller (PTC10K) to stabilize the temperature inside the box. Figure 5 shows the long-term temperature stability in the constant-temperature box is 0.15 ℃ peak-peak during 5.5 days, while the temperature change in the BAM front-end is 1.1 ℃ peak-to-peak. As shown in Fig. 6, the EOM employed in BAM front-end has a half-wave voltage of 6.45 V, and we use a DC-bias controller to set the EOM's work point. Only one EOM was consisted in the first BAM prototype, which will decrease the prototype's dynamic range to several ps. The second EOM will be added after we finished the functional verification of the BAM prototype.

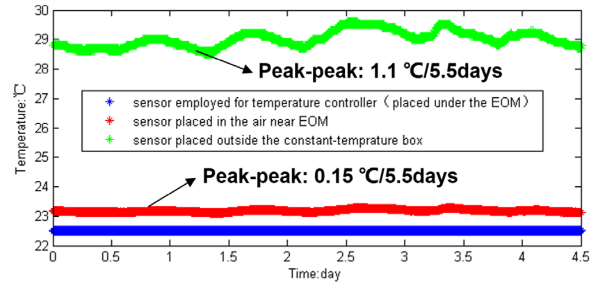

Figure 5: Long-term temperature stability in the BAM front-end.

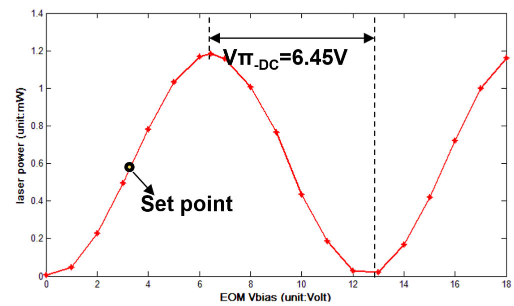

Figure 6: Transmission characteristics curve of the EOM.

BAM Back-end

The BAM back-end is used to detect the amplitude of the laser pulse from EOM. It consists of the ADC sampling clock extraction module, the pulse shaping module, and the high-speed signal processor. Two different high signal processors are employed at different stages of the BAM prototype development. Table 2 lists their main parameters. At this stage, the signal processor (Version A) based on commercial ADC card (FMC150) and FPGA evaluation board (KC705) are employed by the BAM prototype. Table 2 lists its main parameters. The maximum rate of its ADC is only 250 Msps, while the repetition frequency of the reference optical pulse transmitted through the stabilized fibre link to the BAM front-end is 238 MHz. Therefore, two ADCs are employed to sample the peak and baseline of the electrical pulse respectively. A new signal processor (Version B) with higher performance is being developing [4], and will be used in BAM back-end in the near future.

Table 2: Main Parameters of Two High-speed Signal Processor

Parameter	**Version A**	**Version B**
RF channel	2	4
ADC bits	14	16
MAX ADC rate	250Msps	1Gsps
ADC bandwidth	500MHz	1GHz
ADC sampling rate	238MHz	952MHz

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Figure 7 shows the normalized amplitude of the laser pulse detected by the BAM back-end. The laser pulse been detected is from EOM. The red point in Fig. 7 is the right laser pulse been modulated by the pick-up signal. It can be noticed that there are several points adjacent to the red point are also modulated by the trailing of the pick-up signal. Figure 8 shows the normalized amplitude distribution and the amplitude noise of the unmodulated laser pulse (outlined in red rectangle in Fig. 7). The laser amplitude detection resolution of the BAM back-end is 0.5% rms. This result is a little bad, because the jitter of the laser pulse's normalized power is only 0.03% rms, which means the BAM back-end contributes most of the noise. Next, we will optimize the design of the pulse shaping module and update the signal processor to decrease the noise level.

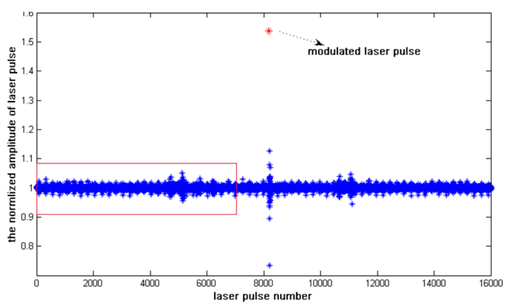

Figure 7: Normalized amplitude of the laser pulse detected by BAM back-end.

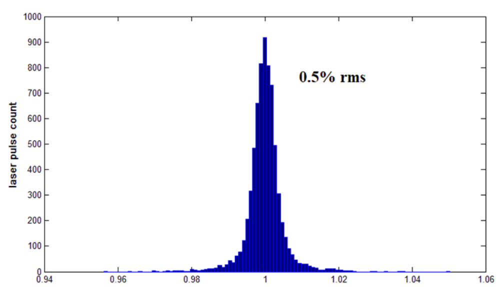

Figure 8: Normalized amplitude distribution of the unmodulated laser pulse.

BEAM TEST FOR BAM PROTOTYPE

The beam test for BAM prototype was carried out at SXFEL. Two oppositely placed 18 GHz pick-up electrodes are combined in a RF combiner and be transmitted through a 22 m RF cable to the BAM front-end. Figure 9 shows the arrived RF signal observed by a 5 GHz-bandwidth-oscilloscope. This RF signal is then sent through a voltage limiter to the RF port of EOM. By scanning the phase between the optical pulse and RF signal in EOM, and detecting the normalized amplitude of the modulated laser pulse. We obtain the "normalized laser amplitude versus time" curve shown in Fig. 10. The blue curve is corresponding to the RF signal attenuated by 10 dB, while the red curve is corresponding to the RF signal without attenuation. The two curves match well. The red curve's slope at the point corresponding to the first zero-crossing point of RF signal is about 55 fs/(%modulation). With the measured laser amplitude detection resolution of the prototype (0.5% rms), the resolution of the first BAM prototype can be estimated to be about 27.5 fs rms.

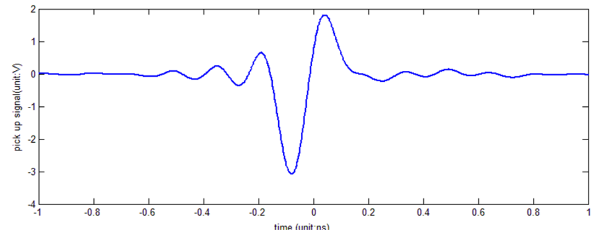

Figure 9: The RF signal observed by a 5 GHz-bandwidth-oscilloscope (electron charge is 500 pC).

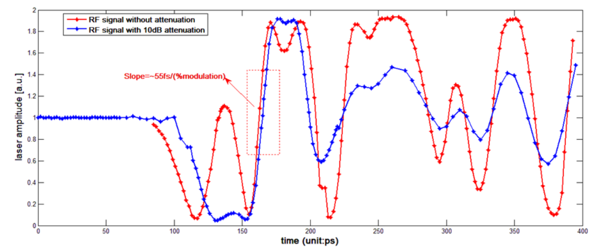

Figure 10: Scan of laser pulse over the RF signal.

SUMMARY

We report the development of the first prototype of BAM for SHINE, as well as the preliminary beam test result. At present, we have finished the development of the 35 GHz pick-up electrodes and its measured bandwidth can achieve up to 40 GHz. Meanwhile, BAM prototype based on 18 GHz button type pick-up has been installed on SXFEL for beam test. The beam test result shows that the laser amplitude detection resolution of the BAM prototype is 0.5% rms, while the coefficient of the normalized laser amplitude versus time is about 55 fs/(%modulation). These two factors determine the estimated resolution of the BAM prototype is about 27.5 fs rms. Next, some efforts will be made to improve the resolution of the prototype. And we also plan to assemble another BAM prototype and use two BAMs to carry out the resolution verification in the near future.

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