

PRELIMINARY RESULTS OF THE BUNCH ARRIVAL-TIME MONITOR AT SXFEL*

Jinguo Wang^{1,2}, Bo Liu^{1,†}

¹Shanghai Institute of Applied Physics, CAS, Shanghai, China

²University of Chinese Academy of Sciences, Beijing, China

Abstract

Based on an electro-optical intensity modulation detection scheme, a Bunch Arrival-time Monitor (BAM) is under study at Shanghai soft X-ray Free Electron Laser (SXFEL) to meet the high-resolution requirements of the measurement of bunch arrival time. The first BAM is installed and is being tested at the SXFEL upstream of the first short undulator (modulator) near the seed laser injection point. In this paper, we present the basic working principle, the design of the BAM system and report the preliminary test results.

INTRODUCTION

The Shanghai soft X-ray Free Electron Laser (SXFEL) currently under commissioning is a test facility for future development of hard X-ray FEL facility. SXFEL will be upgraded to a soft X-ray FEL user facility for the study of physics, chemistry, materials science and biology [1]. With total length of 532 m, the SXFEL-user facility is designed with 2-20 nm wavelength range and <100fs pulse duration. In order to control longitudinal stability of the electron bunch, a beam-based feedback system for the electron bunch is necessary. Crucial electron bunch arrival time information for the feedback system is derived from the bunch arrival-time monitor at several special locations and is used to correct the RF phase/amplitude of the accelerating structures. The BAM stations will be critical longitudinal diagnostic tools for SXFEL operation in the future.

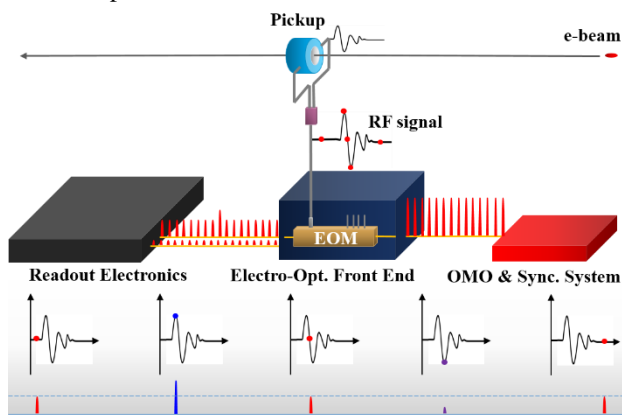


Figure 1: The principle of electro-optical intensity modulation scheme

* Work supported by National Key R&D Plan (2016YFA0401900)

† liubo@sinap.ac.cn

BUNCH ARRIVAL-TIME MONITOR AT SXFEL

The principle of the BAM for detecting the arrival time of the electron bunches is illustrated in Figure 1 [2, 3, 4]. The transient RF signal from the combination of two broadband pickups is fed into a Mach-Zehnder type electro-optical intensity modulator (EOM), which will modulate the amplitude of reference laser pulses proportional to the RF amplitude. Then the readout electronics samples the modulated and unmodulated (temporally outside the RF signal range) laser pulses and calculates the normalised amplitude to each preceding bunch. Therefore the bunch arrival time jitter is derived from the normalised amplitude of the reference laser pulses. The BAM system consists of three comprehensive subsystems, i.e. the RF front end, the electro-optical front end and the readout electronics. The first BAM is installed at the SXFEL upstream of the first short undulator (modulator) near the seed laser injection point (see Figure 2).

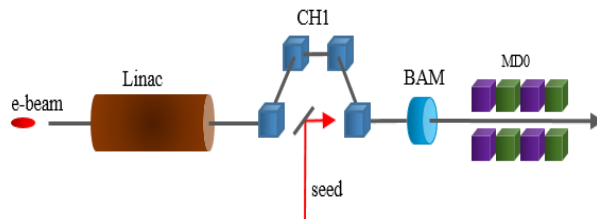


Figure 2: BAM installation location at SXFEL

The RF Front-End

When an electron bunch passes a pickup cavity, a pickup antenna captures a broadband, bipolar RF voltage signal. The zero crossing slope of the pickup's voltage signal is proportional to the signal amplitude and is an important factor in defining the resolution of the BAM [5]. The slope can be increased either by increasing the signal voltage amplitude or the bandwidth of the pickup cavity [3]. Through combining the RF signals of opposite pickup antennas, the signal amplitude can be increased to improve the BAM resolution. However, due to the limitation of microwave device technology, the maximum voltage is rather limited and increasing the bandwidth of pickup cavity is a better way. Therefore, it is necessary to select a larger bandwidth feedthrough to design the BAM pickup cavity.

In our pre-system commissioning, we used a ready-made reference cavity of CBPM as a BAM pickup cavity.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

The Electro-Optical Front-End

The electro-optical front end is the core of the BAM system. The electro-optic modulation is performed in this subsystem, and the bunch arrival time information carried by the RF signal is transferred into the amplitude of the reference laser pulse. Figure 3 shows the schematic of the electro-optical front end. The electro-optical front end is located near the pickup cavity as close as possible in order to reduce the influence of RF cable attenuation and temperature drift. The electro-optical front end has two inputs, the ultrashort laser pulses from the synchronization system and the RF voltage signal from the RF front end. Presently only one Photline MXAN-LN-10 type EOM inside the BAM chassis was adopted because there is only one pair of pickups of the CBPM reference cavity. Inside the BAM chassis the laser pulses pass through the first General Photonics' motorized variable optical delay line (MDL-002) and are divided in equal power into two parts by optical splitter. One part of the laser is sent through a second MDL-002 to the readout electronics for generating a clock signal to ADC, and the other part enters the EOM for amplitude modulation. EOM has an electro-optic crystal which is very sensitive to temperature. Tiny temperature fluctuations can cause the operating point voltage of the electro-optical crystal to drift. Therefore, active temperature stabilisation control of the optical components in the chassis must be performed.

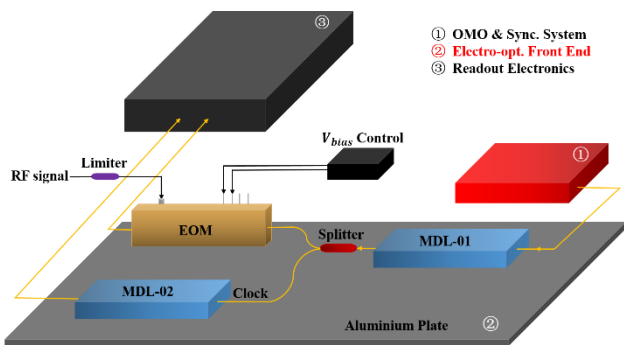


Figure 3: Layout of the electro-optical front end

The Readout Electronics

The purpose of the readout electronics is to further process the amplitude modulated pulse signal from the electro-optical front end (see Figure 4). The laser pulses from the EOM channel are converted to electrical pulses by using a high bandwidth photodetector. After conditioning the electrical pulses are divided into two symmetric ways to two channels of the ADC FMC daughter card. The two ADC channels of the daughter card sample the peak and the baseline of the pulse signal respectively, but a slight phase shift is required for the clock signals of these two channels. The clock signal that is used to clock the ADC and synchronize with the EOM channel is derived from the same laser pulses split at the electro-optical front end. The ADC FMC daughter card (FMC150) is based on TI's ADS62P49 dual channel 14-bit 250Mps ADC, which is enough to simultaneously

sample both peak and baseline of the 238 MHz laser pulses.

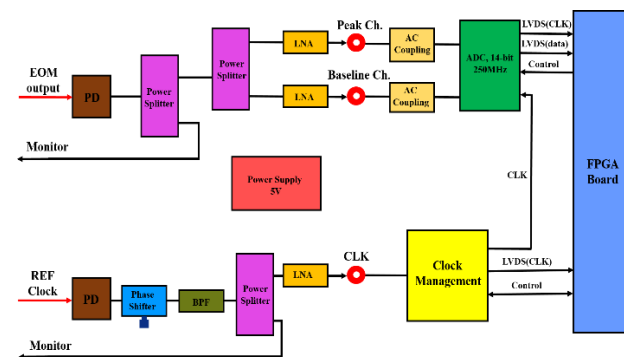


Figure 4: Layout of the Readout Electronics

PRELIMINARY RESULTS

Preliminary test of the BAM system has been performed at SXFEL without the electron bunches. In this section we report the preliminary results about the electro-optical front end and the readout electronics. Due to the temperature and humidity sensitivity of the fiber-optical components, we have conducted effective physical isolation and controlled the temperature stability. In the BAM chassis an aluminium plate is temperature stabilized to 5.5 mK (rms) over one hour and 89 mK (rms) over a week (limited by ambient temperature fluctuations and measurement accuracy, see Figure 5).

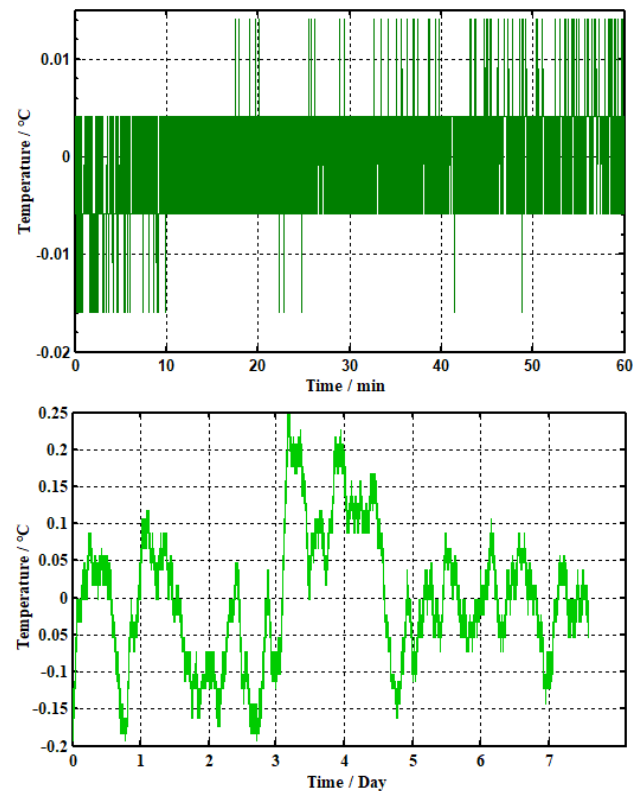


Figure 5: The temperature change of the aluminium plate.

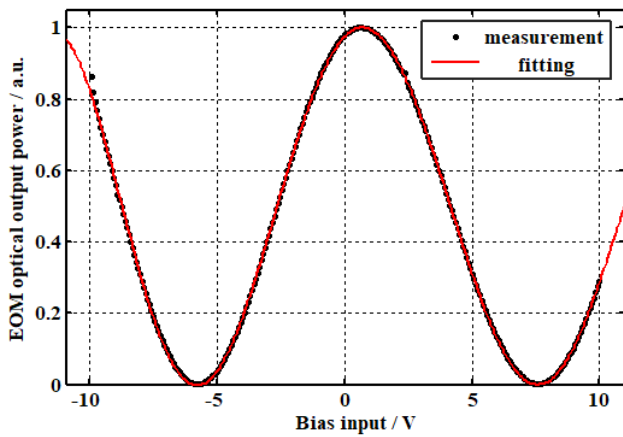


Figure 6: The measured transmission curve of EOM

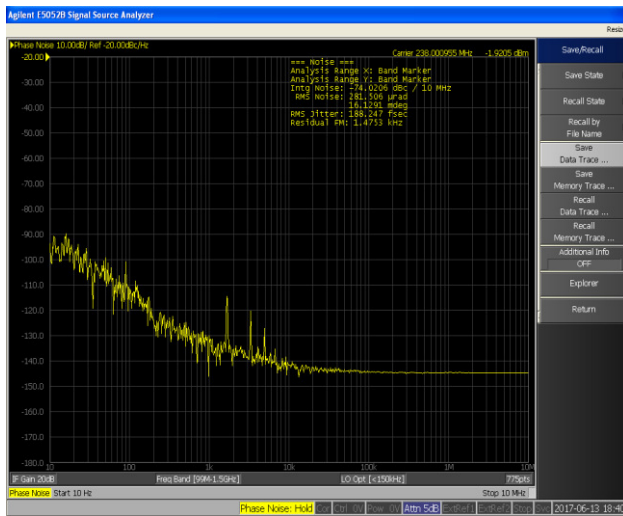


Figure 7: Clock phase noise measured by E5052B

EOM is a key optical device in the BAM system. Many parameters will also affect the resolution of BAM. A higher resolution of the BAM system requires a wider bandwidth (>30GHz), a smaller half-wave voltage $U_{\pi,bias}$, and a larger modulation depth (r , approximately 100%) of the EOM. The transmission curve of Photline MXAN-LN-10 type EOM has been measured without modulation voltage applied to the RF port (see Figure 6). According to the normalized data, the modulation depth r of the EOM is determined to be 99.8%, and the half-wave voltage of $U_{\pi,bias}$ is calculated to be 6.35V. In addition to the zero-crossing slope of the RF signal from the pickup cavity, the laser pulse amplitude noise is another important factor in determining the resolution of the BAM system. The optical master oscillator (OMO) provides amplitude stabilized laser pulses (<0.2% rms, <0.5% pk-pk). Therefore, the amplitude noise of the laser pulses is mainly determined by the amplitude detection accuracy of the readout electronics, especially related to circuit electronics noise, the resolution and SNR of the ADC and electromagnetic interference. The SNR of the ADC is closely related to the performance

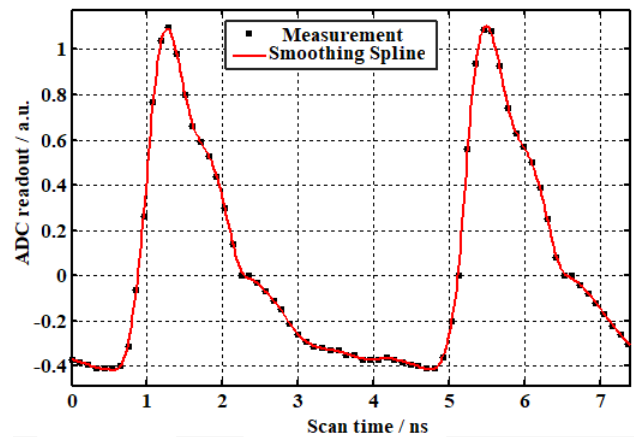


Figure 8: The shape of the laser pulses after scanning

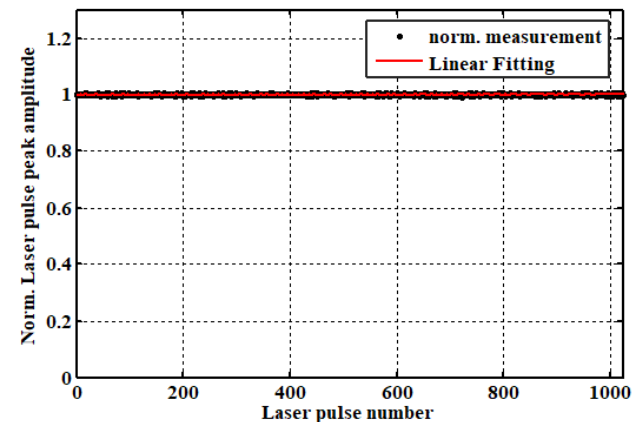


Figure 9: The normalized amplitude noise of laser pulses

of the clock signal. The clock reference signal from the electro-optical front end provides the extremely low phase noise clock for ADC. The phase noise of the clock measured by E5052B is 188 fs (Figure 7), from which a total noise of 237fs can be calculated combining the ADC's aperture jitter t_j (145fs) [6]. The entire readout electronics was evaluated by measuring the laser pulses (see Figure 8). The real amplitude of the laser pulse is calculated by subtracting the baseline amplitude from the peak amplitude of the pulse. As Figure 9 shows, the normalized instantaneous amplitude noise of the laser pulse can be determined with an accuracy of about 0.28 % (rms).

CONCLUSION AND OUTLOOK

The first prototype of bunch arrival-time monitor at SXFEL has been assembled and is currently being tested without electron bunches. The performance of a non-dedicated pickup cavity used in the test will seriously restrict the performance of the BAM. A design of a dedicated high-bandwidth pickup cavity is urgent. Further tests with the electron bunches and the performance evaluation of the entire system will be carried out soon. In addition, we will upgrade the readout electronics by using a 16-bit, 500-MHz ADC to improve the amplitude noise performance.

REFERENCES

- [1] X-ray Free-Electron Laser Test Facility Conceptual Design Report, (2015).
- [2] F. Loehl et al., "Electron Bunch Timing with Femtosecond Precision in Superconducting Free-Electron Laser", *Phys. Rev. Lett.*, 104, 144801 (2010).
- [3] F. Loehl, "Optical Synchronization of a Free-Electron Laser with fs Precision", Ph.D. thesis, Phys. Dept., University Hamburg, Hamburg, Germany, 2009.
- [4] M. K. Bock, "Measuring the Electron Bunch Timing with fs Resolution at FLASH", Ph.D. thesis, Phys. Dept., University Hamburg, Hamburg, Germany, 2013.
- [5] A. Kuhl et al., "Analysis of new pickup designs for the FLASH and XFEL bunch arrival time monitor system", MOPD34, Proceedings of DIPAC2011, Hamburg, Germany.
- [6] ADS62P49, <http://www.ti.com/lit/ds/symlink/ads62p29.pdf>

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.