THE APPLICATION OF BEAM ARRIVAL TIME MEASUREMENT AT SXFEL *

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Abstract

The Shanghai soft X-ray free electron laser (SXFEL) is able to generate high brightness and ultra-short light pulses. The generation of the light sources relies on the synchronization between seed laser and electron bunch. Beam arrival time play an important role to keep the synchronization. For the SXFEL, a beam arrival time resolution under 100 fs is required. In this paper, the application of beam arrival time measurement scheme at SXFEL has been presented. Especially, a two-cavities mixing scheme to measure the beam flight time or pseudo beam arrival time has been proposed and compared with the typical RF phase detection scheme. The experiment results of the two scheme based on the dual-cavities BAM have also been discussed.

INTRODUCTION

The Shanghai Soft X-ray Free-Electron laser facility (SXFEL) is under commissioning now [1]. Figure 1 shows the layout of the SXFEL-TF. The main parameters of SXFEL-TF is shown in Table 1.

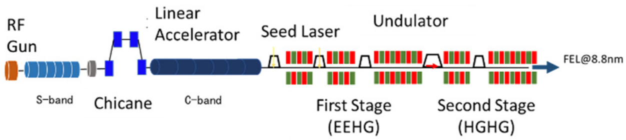

Figure 1: Electron beam characteristic.

Table 1: Main Parameters of SXFEL-TF

Parameter	Value	Unit
Beam energy	0.84	GeV
Beam charge	0.5	nC
Bunch length	~0.5	ps
Pulse repetition rate	10	Hz
Peak current	~ 0.5	A

For the FEL facility, its operation relies on the precise synchronization between the electron bunches and the seed laser pulses in three-dimensional space. Its longitudinal position can be measured by a beam arrival time monitor. The measured beam arrival time can be applied for feedback to adjust the timing of seed laser and also to reduce the timing jitter of accelerator. And the beam arrival time can be used to correct for timing drifts from the accelerator to the experiments[2]. Currently, there are typically two schemes to measure the beam arrival time, electron-optical detection scheme and RF cavity detection scheme. Although the electron-optics detection scheme can acquire better performance, it biggest limitations is its great complexity and quite expensive. In contrast, the RF cavity based detection scheme is simple and inexpensive. In addition, its best resolution can be better than 13 fs.

This paper will focus on the discussion of the RF-phase detection scheme. In detail, the scheme selection, dual-cavities design, fabrication, installation, and beam arrival time experiment as well as beam flight time experiment have been presented.

BEAM ARRIVAL TIME MEASUREMENT SCHEME

The typical RF cavity phase detection scheme is quite mature. Several FEL facility have conducted the research of beam arrival time with this scheme, such as LCLS[3], SACLA[4], PAL-XFEL[5]. Figure 2 gives the diagram of a typical RF cavity based phase detection scheme.

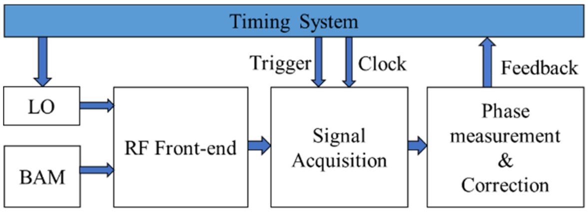

Figure 2: Diagram of a typical RF cavity based phase detection.

The typical BAM system consists of a narrow-band beam arrival time monitor, a reference signal, an RF front-end electronics, a signal acquisition system, and a phase processing/correction system. When an electron bunch passing through the BAM, a variety of electro-magnetic field modes will be excited. Typically, the strongest mode is TM010, a centro-symmetrical mode, whose signal strength is generally proportional to the bunch charge while independent of bunch offset within a paraxial approximation. However, single arrival time phase is meaningless, only when it is relative to a reference time. The two signals, a cavity signal and a reference signal, then be mixed to an intermediate frequency (IF). The beam arrival time can finally be evaluated via a signal acquisition system and phase processing system. However, its limitation is requiring a reference signal with high phase stability. Normally, the reference signal needs to be transmitted over a long dis-

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tance and the thermal expansion of the conventional material is about 30 fs/℃[2]. For SXFEL, a high performance reference signal is not available at present. Especially, the flight time of the electron beam is significant in some special cases, such as in the chicane section of a SASE self-seeding FEL. Therefore a two-cavities mixing detection scheme is proposed in this paper. Figure 3 shows the diagram of a two-cavities mixing based phase detection scheme. The diagram contains two scheme: using a BAM installed at the injection exit instead of a reference signal to measure the pseudo beam arrival time; using two BAM installed at the entrance and exit of the chicane separately to measure the beam flight time.

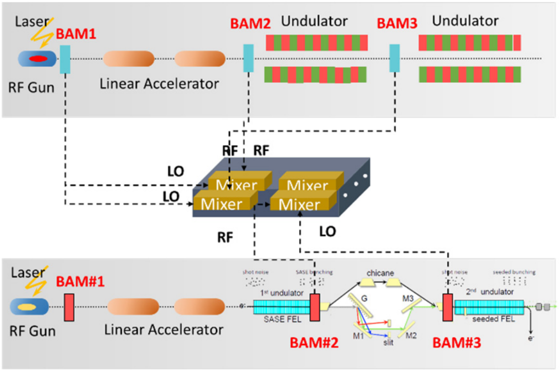

Figure 3: Diagram of a dual-cavities mixing based phase detection.

Considering the above two schemes, one BAM has to be equipped with two frequency so as to realize two-cavities mixing. Therefore, a dual-cavities BAM has been designed and fabricated. Moreover, four sets of BAM have been installed at the SXFEL facility. Two of them are installed near the injection, the other two installed at the modulator section. Figure 4 presents the BAM diagram. Table 2 gives the fundamental parameters of the BAM.

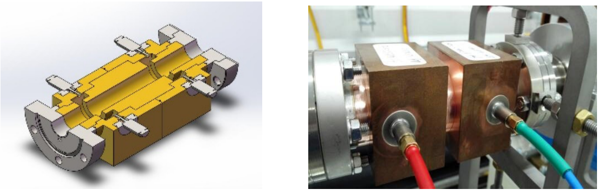

Figure 4：(Left) Schematic diagram of the BAM; (Right) The photo of the fabricated BAM;

Table 2: Fundamental Parameters of the BAM

Parameter	Cavity #1	Cavity #2
Frequency/GHz	4685	4720
Bandwidth/MHz	1.0	1.0
Decay time constant/ns	318	318
Q_{load}	4671	4716
Q_0	4796	4835
Q_e	1.8e5	1.9e5
R over Q /Ohm	107	108

BEAM EXPERIMENT

Beam Arrival Time Experiment

The beam arrival time experiment has been conducted with above BAMs. The diagram of the BAM experiment setup has been performed in Fig.5.

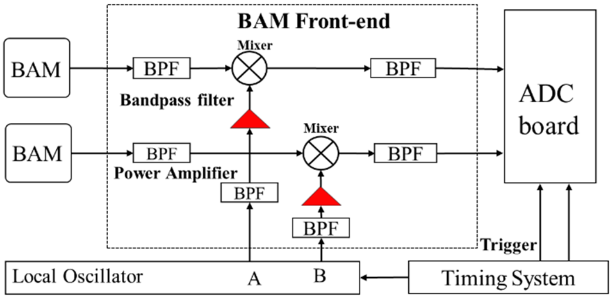

Figure 5: Diagram of the BAM experiment setup.

A 2856 MHz sinusoidal signal serves as the input signal of local oscillator (LO) and output three optional signals, a 119 MHz signal, a 4760MHz signal, as well as a 4640 MHz signal. In this experiment, the LO frequency is determined to be 4641MHz. The frequencies of two cavity signal are both about 4.69 GHz. The generated IF signal then was sampled by DBPM with a sampling rate of 119 Ms/s and 16 bits. In order to reduce the crosstalk between the channels, two IF signal are connected to the channel A and channel D, separately. Figure 6 shows the sampled IF signals and their frequency spectrum. The two IF are 51.9MHz and 52.5 MHz, separately. Thus the frequency difference is about 0.6 MHz.

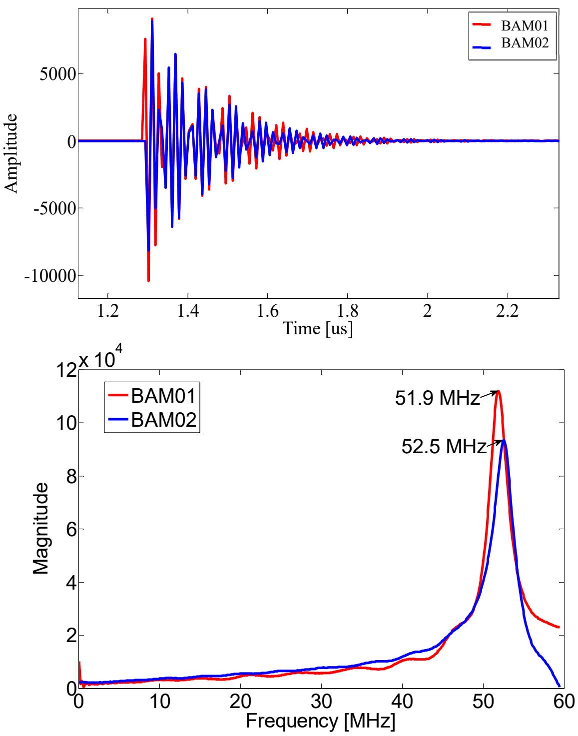

Figure 6: The raw IF signal and their frequency spectrum.

The extracted beam arrival times over 5600 samples (about 1 hour) are shown in Fig.7. And the measured resolution are 1.05 ps and 968 fs, respectively. The two value are larger than expected. However, the two beam arrival times have a strong linear correlation, as shown in Fig.8. The beam flight time resolution between the two BAMs can reach 60 fs via comparing the arrival time, see Fig. 9. Two possible causes are the trigger jitter and the reference signal drift. If the trigger signal stagger one sampling point, there will be a 0.3 radian phase error.

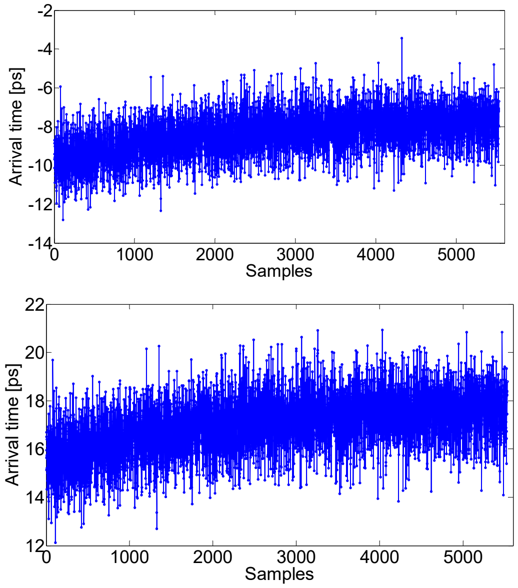

Figure 7: The two arrival time measured by two BAMs. (Above: BAM01 Below: BAM02)

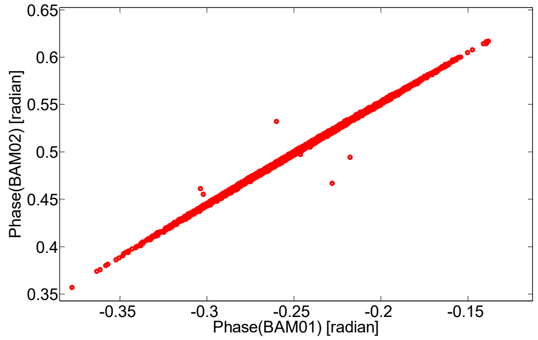

Figure 8: The correlation between the two BAMs

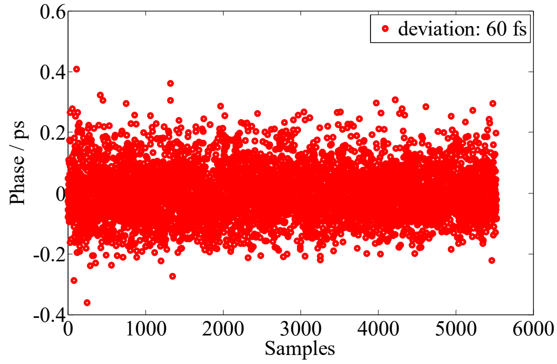

Figure 9: Beam flight time between the two BAMs.

Beam Flight Time Experiment

Using two RF signal induced by two cavities of one BAM, we can evaluate the practicable of the proposed two-cavity mixing scheme. The diagram show in Fig.10. The digitized IF signals show in Fig.11. As discussed above, the IF signal frequency are 35 MHz. The measured beam flight time passing through the two cavities are 37 fs and 66 fs, respectively, as presented in Fig.12. This difference may be related to the BAM port's tiny difference. Moreover, the current RF front-end electronics are put outside the tunnel, thus the RF signals through a long-distance transmission will cause the transmission path inconsistency. Therefore, the RF front-end and signal acquisition system can be placed inside the tunnel in the subsequent optimization experiments to shorten the transmission length.

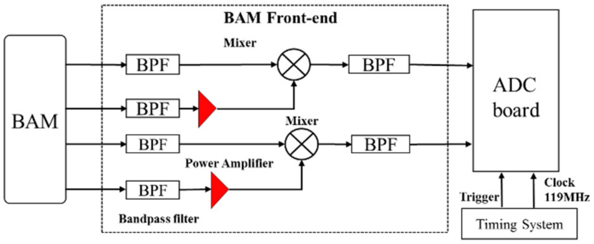

Figure 10: Diagram of the two-cavity mixing setup.

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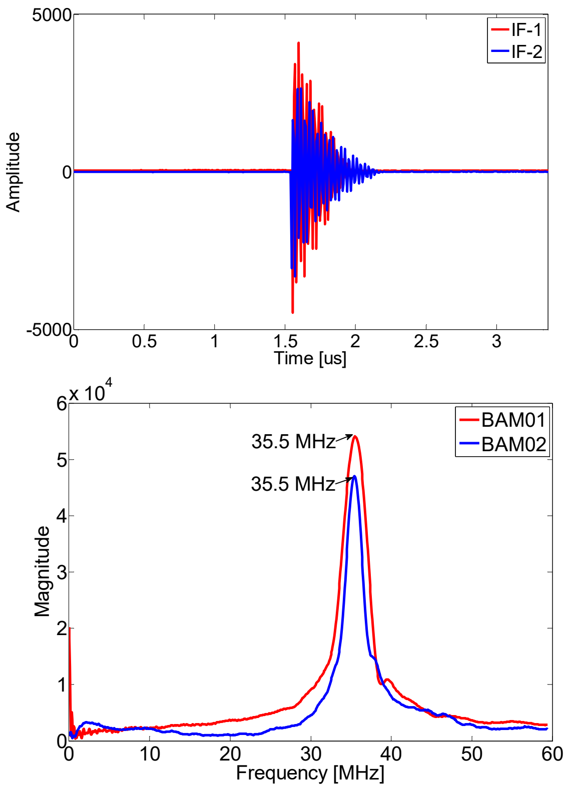

Figure 11: The raw IF signal and the frequency spectrum.

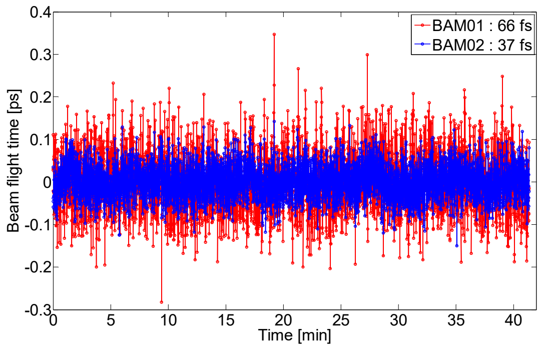

Figure 12: The beam flight time passing through BAM01.

CONCLUSION

In this paper, we have proposed a two-cavity mixing scheme to measure the beam flight time and approximate beam arrival time. Moreover, we have compared the typical RF phase BAM detection scheme and the proposed scheme via conducting the experiment. The typical RF phase detection results shows the beam arrival time resolution of 1.05 ps and 968 fs, respectively, while the beam flight time resolution are 37 fs and 66 fs. Both two mentioned experiments are using the same RF front-end and signal acquisition system. Since the reference signal is the key difference of the whole setup, thus it is suspected to have a great jitter which mainly caused by the transiting process. In the near future, more detailed work will be done, such as optimize the RF cables and the environment of IF signal and signal acquisition system and better results are expected to obtain

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