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BAM SYSTEM AND MACHINE STABILITY AT SXFEL*

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Abstract

Beam arrival time is one of the key fundamental parameters for free-electron laser (FEL) facilities to ensure an accurate synchronization between an electron bunch and a seeded laser. Thus, a high-performance beam arrival time/flight time measurement (BAM) system is indispensable for an FEL facility. A cavity-based BAM system has already been established at the Shanghai Soft-X-ray FEL test facility three years ago. To further optimize the system performance, the impacts of the local oscillator, signal processing window, and temperature around the electronic devices were analyzed, and the related subsystems were upgraded and optimized accordingly. Currently, the upgraded BAM system has been applied at the Shanghai Soft X-ray FEL user facility. This paper will focus on the analysis of the longitudinal beam instability, especially the instability caused by the beam energy jitter by both analytic calculation and beam test. The beam test results show the deviation of beam flight time can reach 10 fs.

INTRODUCTION

Free electron laser, which can generate ultra-high brightness X-ray are working horses for X-ray science research over the world. In recent decades, FELs have developed rapidly worldwide. The development of FEL related key technologies is vitally important and urgent for these facilities. As FEL radiation depends on the interaction between the electron bunch and the seed laser, a real-time high-resolution beam arrival time measurement system is particularly important to monitor the longitudinal position of the electron bunch. A cavity-based beam arrival time measurement system was firstly developed few years ago and is still under optimization [1].

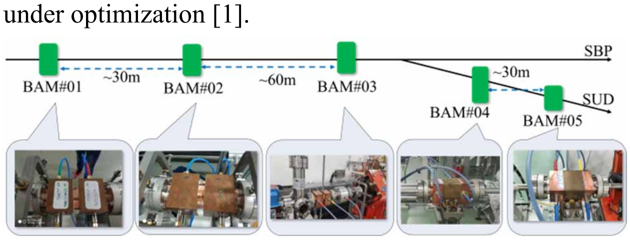

Figure 1: Layout of BAMs at SXFEL.

The phase cavity-based beam arrival time measurement system at SXFEL has been introduced in [2]. Currently, five sets of BAM system have been installed at SXFEL user facility. One of them was installed at the end of the injector, two of them were installed at the LINAC (linear electron accelerator) section, and the other two were installed at one of the undulator lines, as shown in Fig. 1.

There are various timing jitters that can influence the measurement of beam arrival time. There are electron beam timing jitters because of the dispersive effects in the magnetic bunch compressor chicanes. The energy-dependent path leads to the conversion of a beam energy jitter to an arrival time jitter. The energy jitter comes from the amplitude fluctuations and phase jitter of the accelerating fields. Besides, there are jitters of the electron gun and reference clock, as well as the noise of magnet current and so on. All these are what to be measured. In addition, there are possible factors related to our system. For example, the poor stability of reference signal, the error caused by phase extraction algorithm, poor performance of local oscillator and the jitter of clock and trigger signal as well as the environment disturbance. In summary, all these factors will contribute to measurement uncertainty. These are what we are highly suspected and to be tested and improved.

The following section will introduce the system performance of the upgraded BAM system in detail. Furtherly, the longitudinal beam instability will be evaluated with this system.

BAM SYSTEM

Each BAM consists of two cavities working at different frequencies. Class A cavity works at 4.685 GHz and Class B cavity works at 4.72 GHz. The frequencies of Class A and Class B cavities range from 4.6848 GHz to 4.6872 GHz and 4.7204 GHz to 4.7290 GHz, respectively. The maximum frequency deviations of Class A and Class B cavities are 2.4 MHz and 8.6 MHz, respectively. Similarly, the maximum bandwidth deviations of Class A and B cavities are 0.09 MHz and 0.18 MHz, respectively.

As described in [3], the beam arrival/flight time measurement system has been optimized before. Using a strictly phase-locked local oscillator, the measured phase noise (RMS) of LO signal and clock signal have improved from ps to fs. Besides, the relation between the signal damping time and the optimal signal processing window was studied. The phase measurement uncertainty at the optimal signal processing window could be improved by 41%.

This is the new system setup at LINAC. The new LO is applied here. Beside a new thermostatic cabinet is applied. Both DBPM, LO and RFFE are placed inside it. The peak-to-peak temperature variation of the thermostatic cabinet is about 0.2 degree. We use three BAM's 4685 MHZ cavities as the monitors. The layout is given in Fig. 2. A new LO is used which can generate a LO signal of 4654.2 MHz. Thus, the generated IF signal is about 30 MHz.

Using the abovementioned system setup, the three BAM system were tested at a bunch charge of 100 pC. Figure 3

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shows the variation of beam arrival times over 10 mins of the three BAMs. The measurement uncertainties are 30 fs, 61 and 62 fs for the three BAMs, respectively. Compared with the results before, the system performance has been significantly improved.

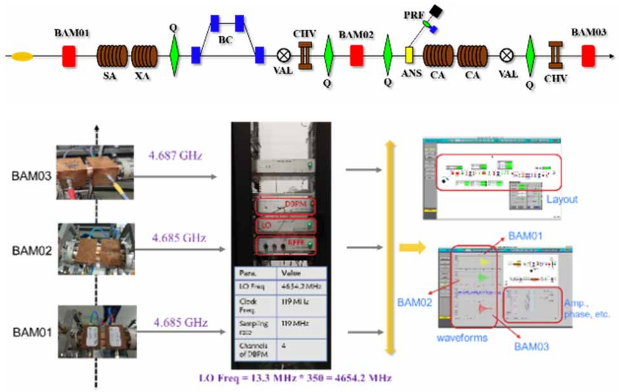

Figure 2: Layout of first three BAMs (BAM01, BAM02 and BAM03) at SXFEL.

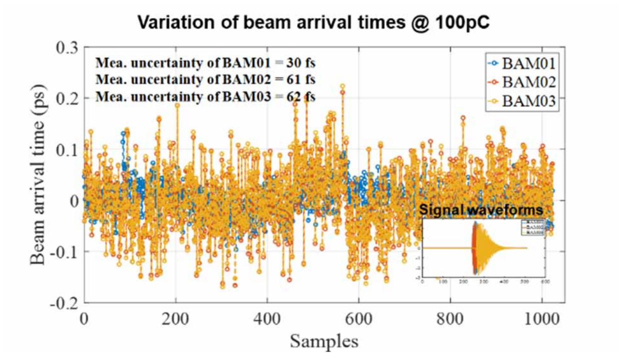

Figure 3: Beam arrival times of the first three BAMs at SXFEL.

BEAM INSTABILITY

As mentioned in Sec. II, the measurement uncertainty of BAM2 is greater than that of BAM01 but close to that of BAM03. To further analyze the reasons for the differences in measurement uncertainty among the three BAMs, the beam flight times were calculated, as shown in Fig. 4. The measurement uncertainties of the beam flight time between the first and the second BAMs, as well as the first and the third BAMs are 64 and 65 fs, while the measurement uncertainty of BFT between the 2# and 3# BAMs is only 10 fs. Given there is a chicane between the first and second BAMs, the beam energy jitter might be the main contribution for the beam instability when it is passing through the first two BAMs. When it is traveling through the last two BAMs, the measurement uncertainty probably contributed by the system noise and beam orbit fluctuation.

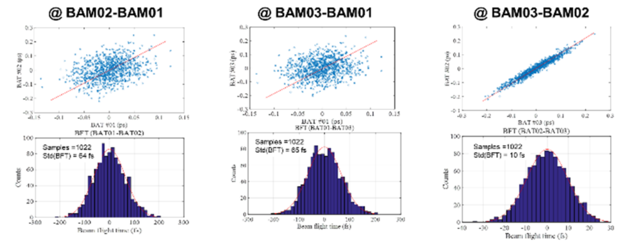

Figure 4: Beam flight time measurement uncertainty among the three BAMs.

Beam Orbit Fluctuation

To evaluate the impact of beam trajectory on beam arrival time, the parameters of the correction magnet (upstream of S01) are adjusted to change the beam trajectory, with energy and other parameters unchanged, and the beam arrival time are synchronously measured. The layout of the BAMs, SBPMs are shown in Fig. 5.

Comparing the change in beam arrival time (IN-BAM01/02/03) with the change in beam position (SBPM06). The positions of 200 bunches (-1 mm to +0.7 mm) showed significant changes, but there was no significant change in the beam arrival time. Therefore, the beam arrival time is independent of the beam trajectory.

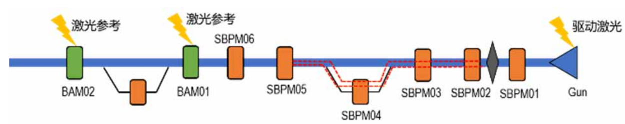

Figure 5: A lengthy figure caption that spans multiple lines is justified.

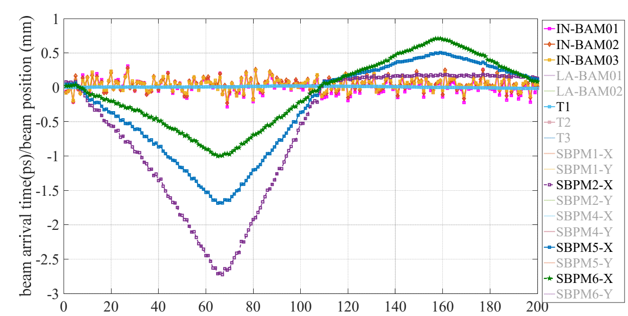

Figure 6: The variations of beam arrival times and beam positions.

Beam Energy Jitter

As discussed in [4], a beam-based test was conducted at SXFEL with a bunch charge of 500 pC. A total of 14 measurements are conducted. For each measurement (No. 1 to No. 14), over 1000 data acquisitions of beam arrival/flight time were performed. The variation of the average beam arrival time of BAM01 with the beam energy does not show dependency between the two parameters, which is under expectation. However, the beam arrival time of BAM02 varies significantly with energy, as shown in Fig. 7. The peak-to-peak value is 6.5 ps. The focus turns to whether the beam arrival time has a linear dependence on the beam energy. Fortunately, as presented in Fig. 8,

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they show a very good linear relationship with a linear factor k of 0.692 ps/MeV. The fitting uncertainty is 0.018 ps/MeV.

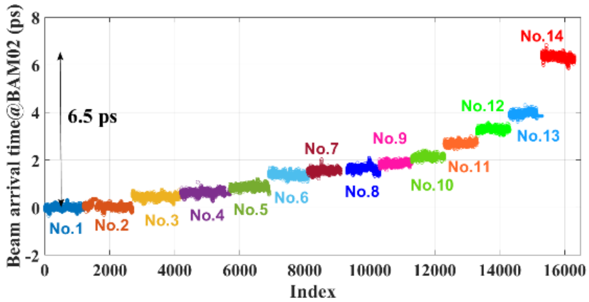


Figure 7: The variation of beam arrival time of BAM01 over 14 measurements.

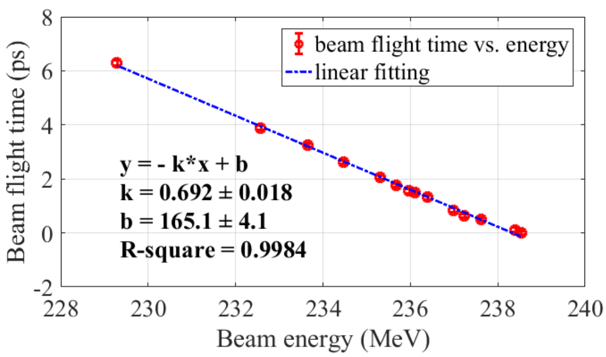
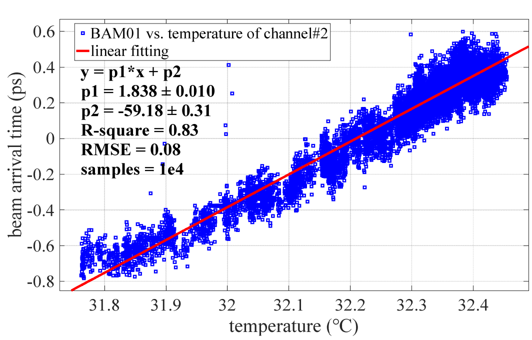
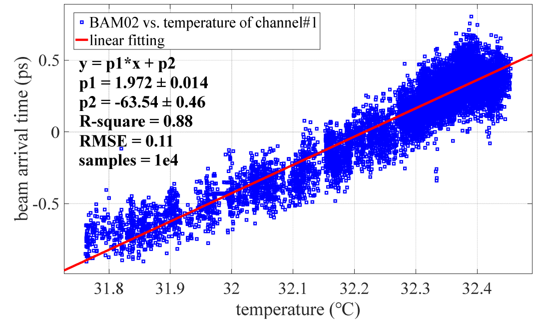


Figure 8: Correlation between the time-of-flight and beam energy.

Temperature Jitter

In addition, we also studied the influence of the temperature around the electronic devices on the beam arrival time measurement with a resistance temperature detector (RTD) temperature sensor. The electronic devices include RFFE, LO and DBPM. Both of them are outside the tunnel. The test results show an approximately linear relationship between the temperature and the beam arrival time. The measured linear factors are about 1.8 ps per celsius degree for the three BAMs, as shown in Fig. 9. Therefore, a high-performance thermostatic cabinet is necessary for the long-term stability of the system.





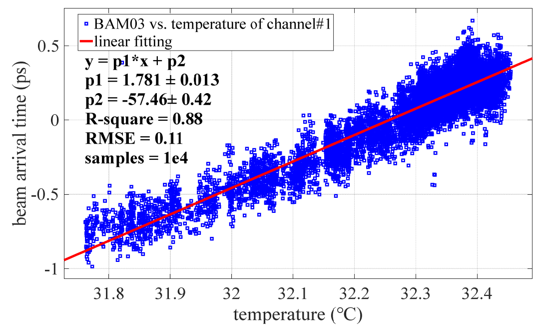


Figure 9: Correlation between the beam arrival time and temperature.

CONCLUSION

The flawed cavity-based beam arrival time measurement systems at SXFEL-TF have been optimized from several aspects. The improved beam arrival time measurement systems have been utilized at SXFEL-UF, and the measured system uncertainty is only 10 fs. The beam flight time test results show an obvious beam instability. The beam flight time deviation with and without a magnetic chicane are 64 fs and 10 fs, respectively. The energy jitter is a main contribution, which can contribute 33 fs to 65 fs to the beam flight time rms jitter, while the beam position jitter can be ignored.

REFERENCES

[1] S. S. Cao *et al.*, "Dual-cavity beam arrival time monitor design for the Shanghai soft X-ray FEL facility", *Nucl. Sci. Tech.*, vol. 30, no. 72, Apr. 2019. doi:10.1007/s41365-019-0593-3

[2] S. S. Cao *et al.*, "The Application of Beam Arrival Time Measurement at SXFEL", in *Proc. IBIC'18*, Shanghai, China, Sep. 2018, pp. 342-345. doi:10.18429/JACoW-IBIC2018-WEOA04

[3] S. Cao *et al.*, "Optimization of Beam Arrival and Flight Time Measurement System Based on Cavity Monitors at the SXFEL", *IEEE Trans. Nucl. Sci.*, vol. 68, iss. 1, pp. 2-8, Oct. 2020. doi:10.1109/TNS.2020.3034337

[4] S. Cao *et al.*, "An application of a cavity-based beam arrival time measurement system: Beam energy measurement", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 1045, p. 167456, Jan. 2023. doi:10.1016/j.nima.2022.167456