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SXFEL LINAC BPM SYSTEM DEVELOPMENT AND PERFORMANCE EVALUATION*

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Abstract

Shanghai Soft X-ray Free Electron Laser (SXFEL) is a test facility to study key technologies and new FEL physics. In order to deliver high quality electron beams to the undulator section, a high resolution (better than 10 microns with 200 pC beam) Linac beam position monitor system has been developed. The system consists of stripline pickup and custom designed DBPM processor. The hardware and software architecture will be introduced in this paper. The online performance evaluation results will be presented as well.

BACKGROUND

SXFEL

SXFEL is one of the high-gain FELs constructed in China. Key technologies have been tested through prototype developments. Based on the research and development prototype of hard X-ray FEL. The construction of the user facility in soft XFEL has already finished. The SXFEL facility consists of an electron injector with a thermionic cathode, main accelerate section including C-band high-gradient accelerators along with S-band accelerators, and in-vacuum undulators. Fig. 1 is SXFEL injector layout [1]. SXFEL

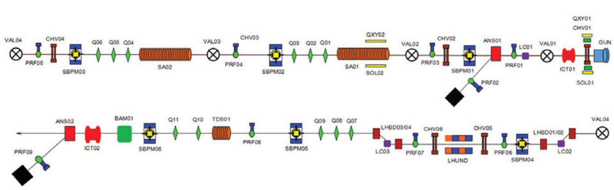

Figure 1: SXFEL injector layout.

is designed to generate a coherent x-ray beam using a self-amplified spontaneous emission (SASE) process. Below is the baseline parameters of SXFEL. In order to meet the harsh demands, the beam diagnostic system achieving high precision resolution is one of the most important technical issues. Demands for the precise measurement of the resolution of the SXFEL LINAC system.

LINAC BPM System

As the key beam diagnostics tool, BPM systems are widely equipped in all kinds of accelerators. Stripline Beam Position Monitors (SBPM) are main beam diagnostic instruments in SXFEL. There are six SBPMs conducted in SXFEL injector section and nearly thirty SBPMs conducted in LINAC section in injector section used for the measurement and adjustment of beam orbit. Moreover, the sum of four SBPM electrodes signal can also apply in relative beam charge measurement. Fig. 2 is the block diagram of SBPM system. RF cable extract beam signal from SBPM pickup, RF signal conditioning circuit to digital BPM processor.

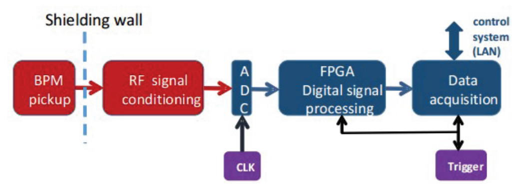

Figure 2: BPM system block diagram

Stripline BPM Since the size of the beam pipe is different, there are two kinds of SBPM with different K values in SXFEL. One of the beam pipe diameter is 16 mm while the K value is 5.24, the other is 25 mm while the K value is 7.59. The installation of the SBPM in SXFEL is different from the BPM installed in SSRF, we adopt horizontal and vertical installation mode. In that way, horizontal and vertical beam position measurement is mutual independence.Fig. 3(a) is the picture of stripline BPM.

Figure 3: Stripline BPM and DBPM processors in SXFEL.

DBPM processor The DBPM processors are custom designed to measure the beam positions, every beam position monitors is connected to a digital BPM processor. The centre frequency of the DBPM processor is 500 MHz, and the bandwidth is 20 MHz. The processor is carried a 16 bit high-resolution ratio ADC and advanced FPGA chip. The arithmetic of beam position is using Hilbert transform to exact the amplitude, using $\Delta - \Sigma$ arithmetic calculate the beam position. Fig. 3(b)is some of the DBPM processors conducted in the SXFEL technical corridor and Fig. 4 is SXFEL edm panel.

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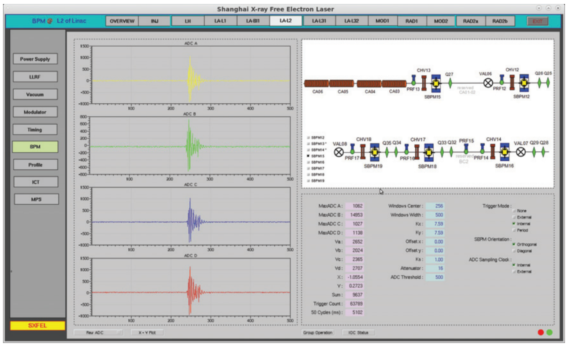

Figure 4: SXFEL EDM panel.

BEAM EXPERIMENT

One of the most important technical issues is to deliver high quality electron beams to the undulator section. The beam position resolution in SXFEL BPM system should be better than 10 µm at 500 pC beam charge. It is also important to using the SBPMs to monitor the SXFEL machine running status.

Target of Beam Experiment

The system consists of stripline pickup and custom designed DBPM processor. The online beam experiment should be used to evaluate the system resolution performances.

Experiment Details

Functionality test The first experiment is designed to check the BPM function in LINAC SXFEL. Inputing a sinusoidal excitation into first quadrupole at injector section to stimulate the beam and collecting all SBPMs signals in one hour.

SBPM resolution evaluation The second experiment is using geometry to measurment the uncertainty of SBPM. The architecture of experiment is shown below Fig. 5. It consists of three SBPMs and three set of DBPM processors. The upper computer carry Linux operating system, using python script to acquire the beam position data from the DBPM processors. The resolution performance can be evaluated using three SBPMs. We select three adjacent SBPMs without accelerating tube showing in Fig. 6. Consider of beam freely drifting, all of the electromagnets between the BPMs were turned off. In that way, the beam throughout the three SBPMs following the simple geometrical relationship. The first and third SBPMs beam position readouts can predict the second SBPM beam position readouts. The beam position resolution of the second SBPM can be measured from the experiment compute. Since the SBPM is the same batch, assuming that the resolutions of the three SBPMs were same, in that way, the position resolution was calculated by the following equation:

$$\sigma_{SBPM} = \frac{L_1 + L_2}{\sqrt{2\left(L_1^2 + L_1 L_2 + L_2^2\right)}} \cdot \sigma_{res} \qquad (1)$$

Where L1 and L2 are the distance between the adjacent SBPMs, and σ_{res} is the standard deviation of the residual distribution [2].

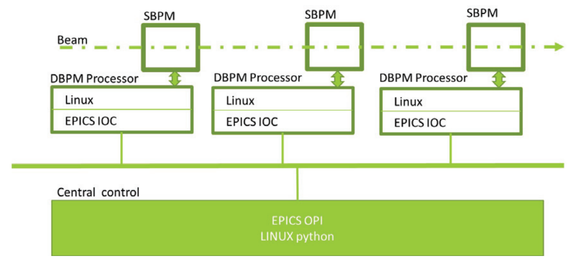

Figure 5: architecture of SBPM resolution evalution system.

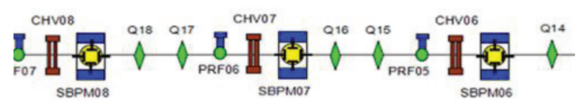

Figure 6: Three adjacent LINAC BPMs installation.

History data analyze The experiment system above has the limitation of SBPM installation condition. Since the principal component analysis (PCA) had been introduced in the accelerator physics and it could be used to get rid of the actual signals. Beam related informations were extracted, performance evaluation can be done with all of the SBPMs in SXFEL Linac BPM system. At normal operation status, gathering all LINAC SBPM readouts to analysis the position resolution.

PERFORMANCE EVALUATION

Fig. 7 is time domain response of SXFEL LINAC BPM at extrinsic motivation situation. According to the figure, the 22 SBPMs are all showing periodicity fluctuation, which means machine status is normal and all SBPMs are working. The Fig. 7 is the time domain of SBPMs.

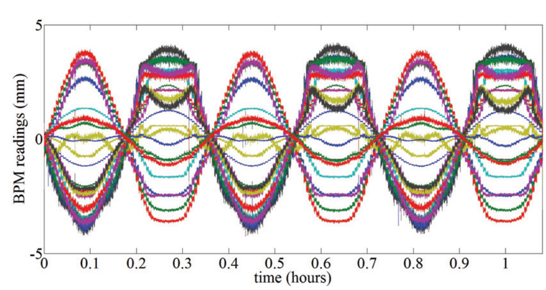

Figure 7: time domain response of SXFEL LINAC BPM.

Fig. 8 is the measurement value of the second BPM vs the expectation value. The standard deviation means the position uncertainties of the three SBPMs. Fig. 9 use histogram

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to show the difference between the expectation value with measurement value.

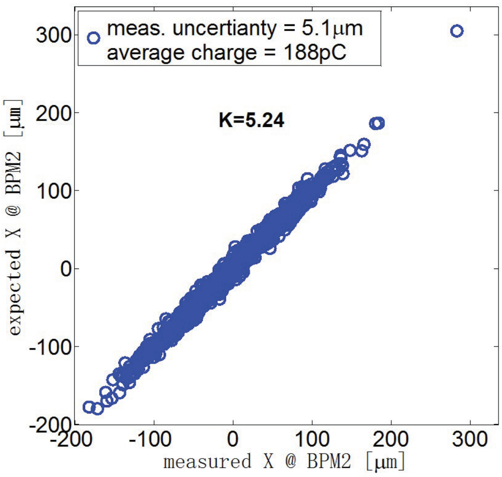

Figure 8: Linear function fitted to evaluate at 188 pC.

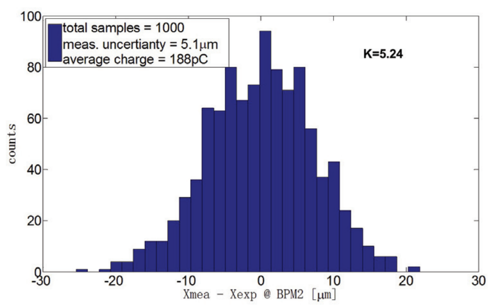

Figure 9: Histogram of position error at 188 pC.

Fig. 10 is using PCA to calculate 22 SBPMs measurement uncertainty. As shown in the figure, all of the evolution performance of LINAC BPM system is better than 10 μs. We also analysis the standard deviation of 22 SBPMs showing in Fig. 11, we pay close attention to SBPM No.4,15,16,17 to study machine status. In Fig. 12, we can observe orbit drift. It provide next step optimized direction in SXFEL.

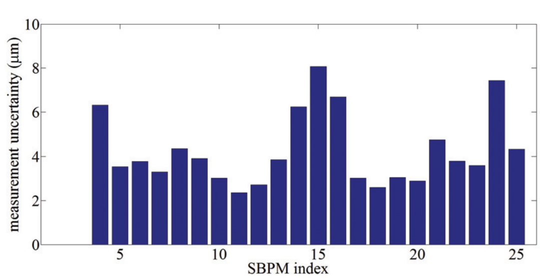

Figure 10: Measurement uncertainty of 22 SBPMs.

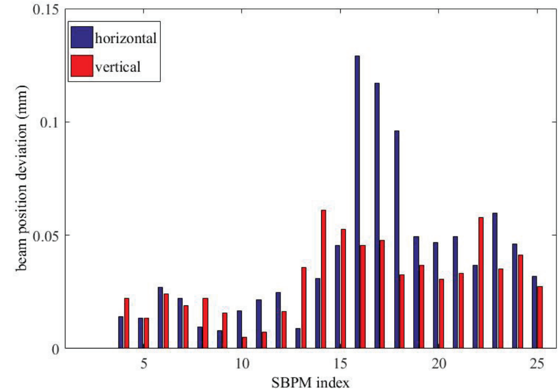

Figure 11: 22 SBPMs position standard deviation.

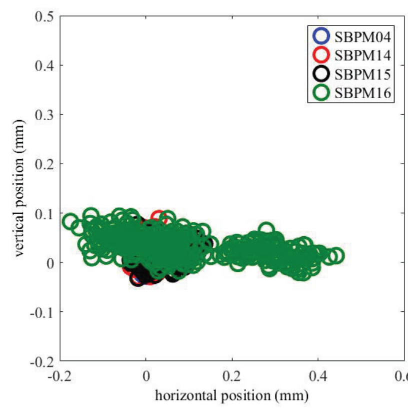

Figure 12: Comparison of several SBPMs position slow drift.

CONCLUSION

In this article, we introduce the SXFEL LINAC BPM system. In order to evaluate the performance of the system, we designed three experiments to measure the resolution and asses running status of the SXFEL LINAC BPM. The design object is 10-microns resolution under 500 pC beam charge. According to our experiments, at normal operation environment, the beam charge could reach 200 pC, the position resolution was less than 10 microns. These results are proving the SXFEL LINAC BPM system reaching the SXFEL facility design target.

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