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THE DEVELOPMENT AND APPLICATIONS OF DIGITAL BPM SIGNAL PROCESSOR ON SSRF *

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Abstract

The development of Digital BPM Signal Processors (DBPM) for SSRF started from 2008. The first prototype for SSRF storage ring was completed in 2012, with turn-by-turn resolution better than 1μm. From 2016 to 2017, SSRF successively constructed two FEL facilities in China, DCLS and SXFEL test facilities. The second version DBPM was developed and used in large scale during this period to meet the requirements of signal processing for stripline BPMs and cavity BPMs. After that, we turned to the development of DBPM for SSRF storage ring based on the second version hardware, including FPGA firmware, EPICS IOC, EDM control panel. The development was completed and tests were carried out in early 2018. Test results showed that the position data is accurate and can monitor beam movement correctly, and online turn-by-turn position data resolution reaches 0.46μm. This paper will introduce the design of DBPM for the SSRF storage ring and the tests carried out to verify the data accuracy and evaluate the system performance.

INTRODUCTION

SSRF is the first 3rd-generation synchrotron light source built in China, which came into service in 2009. The circumference of the storage ring is 432 meters, and the ring contains 20 cells that can serve up to 40 beamlines. The 499.654 MHz RF system produces 720 buckets of which typically 500 contain charge distributed in 4 bunch trains to minimize ion accumulation. There are 7 BPM electronics in each cell totaling more than 140 sets Libera BPM electronics around the ring measuring the beam orbit for beam control and feedback.

SSRF started the development of Digital BPM Processor (DBPM) in 2008. A first version prototype was developed in 2012 for the SSRF storage ring[1]. Later a second version DBPM hardware was developed in 2016[2,3], which was more compact and more versatile. The new DBPM was first used on two FEL facilities, DCLS and SXFEL, in large scale. The development of new SSRF DBPM based on the new version hardware was taken from that design.

Table 1 lists the DBPM requirements based on considering accelerator performance and current technical level. After years of on and off development and improvement, a second version DBPM was developed and tested on SSRF this year.

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Table 1: DBPM Requirements

Requirements	Value
ADC	4 channels, 16bits
Central Frequency	499.654MHz
Sampling clock	External/internal
Sampling rate	117.2799MHz
Turn-by-turn rate	693.964kHz
Trigger	External/internal/period
Signal processing	FPGA
Data	ADC/TBT/FA/SA
Resolution	~1μm@TBT
OS	ArmLinux
Control	EPICS

FIRMWARE AND SOFTWARE DESIGN

The DBPM was designed to provide position data at five different rates, including raw ADC data, turn-by-turn data, 50kHz fast acquisition (FA) data, 10kHz FA data, 10Hz slow acquisition (SA) data. Figure 1 shows the DBPM signal processing diagram, with the processing including four steps, and data rate reduced after each step. Position data is read out in small scale streaming mode or large scale capture mode.

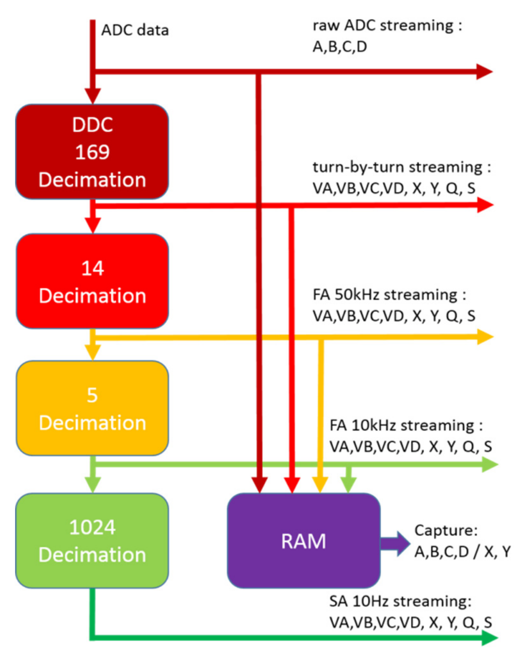

Figure 1: DBPM signal processing diagram.

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Figure 2 shows the EDM control panel for the DBPM system. The left panel shows the streaming readout data waveforms. The upper right section displays some signal information (including max ADC value, trigger count value) and parameter settings (including $K_{x/y}$, offset, attenuator, inner trigger threshold value). The lower right section shows the configuration of the trigger mode (including none, external, internal, period), clock source (internal, external) along with data and display selection.

Figure 3 is the screenshot of turn-by-turn data during injection (left) and SA data output (right).

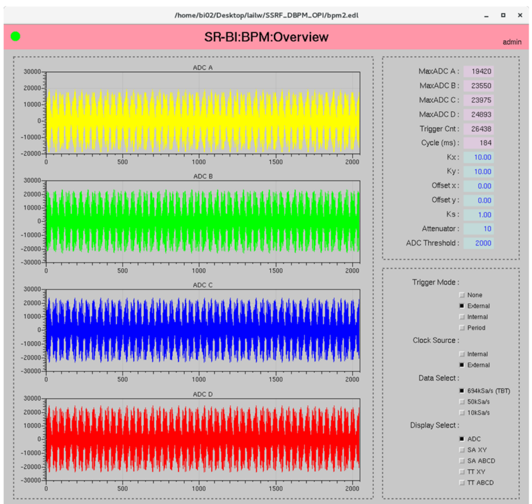


Figure 2: DBPM control panel.

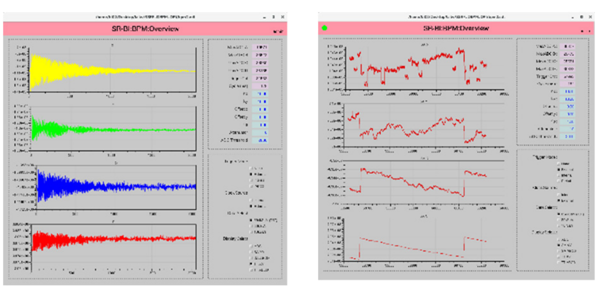


Figure 3: Turn-by-turn data during injection (left) and SA data (right).

VERIFICATION TESTS

The BPM electronics at SSRF include Libera Electron and Brilliance. Brilliance is widely used for its excellent performance where turn-by-turn data resolution reaches 1µm. SSRF online tests have been carried out to verify the accuracy of DBPM processor by comparing the position value between Brilliance and DBPM. The signal of a spare BPM on Cell 11 was divided into two and fed into the Libera Brilliance and DBPM modules. Figure 4 shows the test diagram and field installation picture.

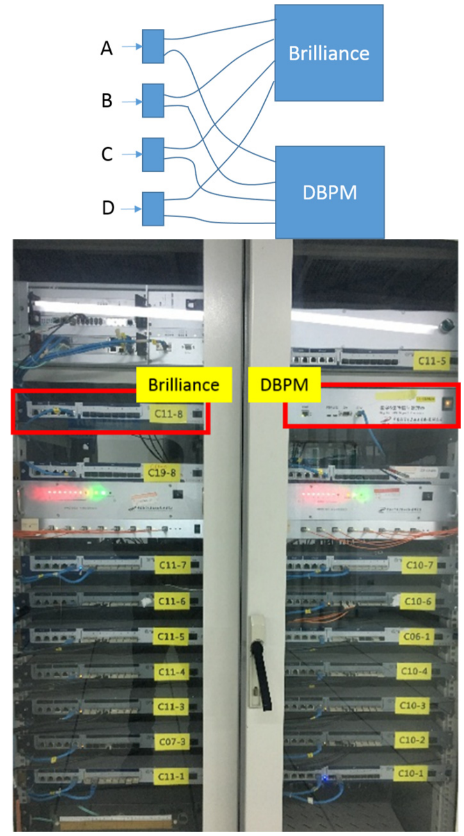
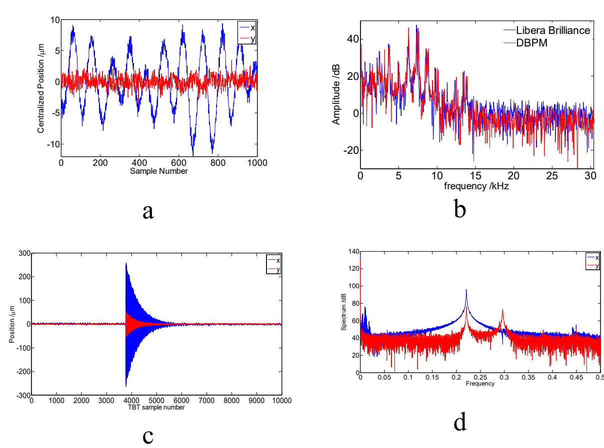


Figure 4: Verification tests and installation.

Test results are shown in Figure 5. Figure 5(a) shows the DBPM turn-by-turn position data waveform. X (horizontal) data shows oscillations compared to Y (vertical) because of energy oscillations in horizontal plane. Figure 5(b) shows the turn-by-turn position data spectrum of Brilliance and DBPM, and they fit quite well. Figure 5(c) is the DBPM turn-by-turn data during injection, the induced oscillation can be seen clearly, and the tune value can be calculated during this time (d). As for the 10Hz SA data, five hours data shows that they fit well (e), and the RMS of the five hour difference is 0.83µm (f).



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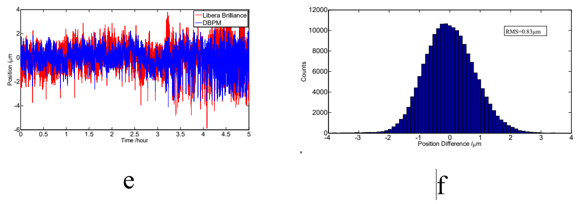

Figure 5: Verification results.

PERFORMANCE TESTS

The DBPM performance evaluation test was carried out as depicted in the block diagram in Figure 6. Input signals include BPM four pickup sum signal and 499.654 MHz RF signal from a signal generator.

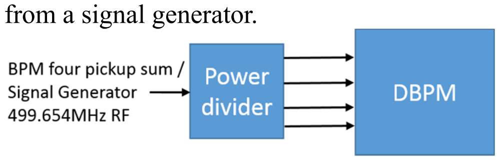

Figure 6: Evaluation test diagram.

Figure 7 shows the performance evaluation results. Figure 7(a) is the turn-by-turn resolution result on SSRF, 0.46 μm rms calculated with 524288 turns. The resolution of FA 50kHz data and FA 10kHz data is 0.19 μm 7(b) and 0.10 μm 7(c), respectively. The benchtop signal generator test result shows that the SA 10Hz data resolution only 43 nm using 600 points.

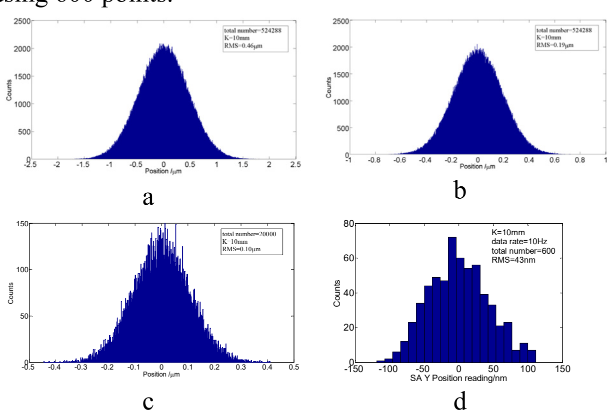

Figure 7: Evaluation results.

CONCLUSION

The development of a new DBPM processor for SSRF is based on new hardware that started at the end of 2017, including FPGA firmware development, EPICS IOC development and EDM control panel design. The second version of the SSRF DBPM is a fully functioning processor which provides ADC data, turn-by-turn data, FA data, SA data, and can be accessed through EPICS.

Online tests were carried out in early 2018 on SSRF. Test results show that DBPM processor can measure the beam orbit accurately when comparing the results with Libera Brilliance. The turn-by-turn data resolution can reach 0.46 μm rms, much better than the first version.

We can draw the conclusion from above results that the new version DBPM meets the requirement of beam orbit measurements on the storage ring, and can be used for beam position control. However, more time and resources are still needed to make the DBPM more stable before final deployment.

At the same time, more applications are being planned and developed based on the same hardware[4,5], including booster DBPM, LINAC DBPM, a smart tune measurement processor, bunch-by-bunch tune measurement and bunch-by-bunch charge measurements with an interleaving technique. Some of these projects have been completed, and some are still in progress. The results will be introduced in the near future.

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