ONLINE EVALUATION OF NEW DBPM PROCESSORS AT SINAP *

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Abstract

In this paper, we report our online evaluation results for new digital BPM signal processors, which are developed for the SSRF and the new Shanghai SXFEL facility. Two major prototypes have been evaluated. The first algorithm evaluation prototype is built using commercial development toolkits modules in order to test various digital processing blocks. The second prototype is designed and fabricated from chips level in order to evaluate the hardware performances of different functional modules and assembled processor.

INTRODUCTION

Digital beam position monitor (DBPM) processor is world wide used in light sources and FEL accelerators [1-3]. Few microns resolution at turn-by-turn (TBT) rate and sub-micron resolution at slow application (SA) rate are achieved for circular accelerators with commercial product [4].

In order to accumulate technologies and enhance capability of instrument development two prototypes of DBPM processors have been initiated since 2008 at SINAP. One prototype is based on commercial ADC evaluation board (ICS1554) to test various signal processing blocks and EPICS IOC interfaces [5]. The other prototype is custom designed and built from chips level to be a hardware frame of processor [6]. The primary target of this processor is SSRF storage ring. But equipped with proper RF front-end this processor could be used for the new Shanghai SXFEL facility. Both prototypes have been completed and passed lab test recently. After that these two prototypes merged together to form a final version ready for online evaluation.

The practical beam signal is totally different with sine wave produced by RF signal generator in lab. Online evaluation has to be performed to verify the functionality and performance of the new DBPM processors. A spare button-type BPM sensor (C15BPM8) in the SSRF ring, which delivering the same signal as other BPMs, is used for this purpose. All function blocks including turn-by-turn, fast application (FA) and slow application are loaded into the new processor to acquire real beam data.

SPATIAL RESOLUTION EVALUATION

500k samples of TBT data, 500k samples of FA data and 3k samples of SA data are acquired to evaluate the spatial resolution of BPM processor. Figure 1 shows the histogram of these data in the vertical plane at 200 mA. Since the distribution of position readings is the combination of processor electronics noise and real beam orbit noise, the actual resolution should be better than σ. That means the TBT resolution of the new DBPM processor is better than 1.4 μm, FA resolution is better than 0.38 μm, and SA resolution is better than 0.21 μm.

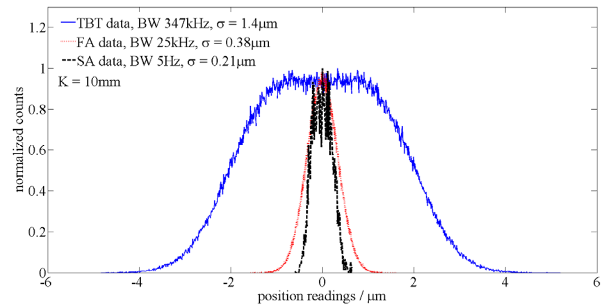

Figure 1: Spatial resolution evaluation online.

Non-Gaussian distribution of TBT data comes from a narrow band noise, which frequency is few tens kHz, produced in the DDC stage. The next optimization will focus on this.

Figure 2 shows the result of TBT resolution evaluation with different beam current. Resolution of 2 μm can be achieved when beam current is larger than 100 mA.

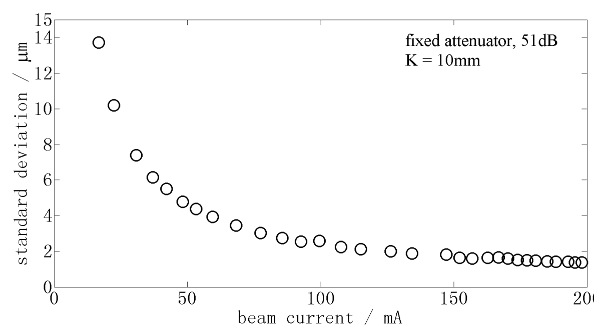

Figure 2: TBT resolution evaluation with different beam current.

TBT APPLICATION

The frequency domain analyze of TBT data is very powerful tools for machine study. All kinds of orbit noise which bandwidth lower than half of revolution frequency will show in the spectrum of TBT data and be identified easily. Combined with exciting kickers, fabric tune value, beta function and betatron oscillation phase advance can be derived from TBT data of multiple BPMs as well. Traditional DDC algorithm based TBT block has been implemented in the new BPM processor to demonstrate the above capabilities. Figure 3 shows the spectra of TBT data at vertical plane captured during injection.

*Work supported by 100 Talents Program of the Chinese Academy of Sciences and National Natural Science Fund (No. 11075198)
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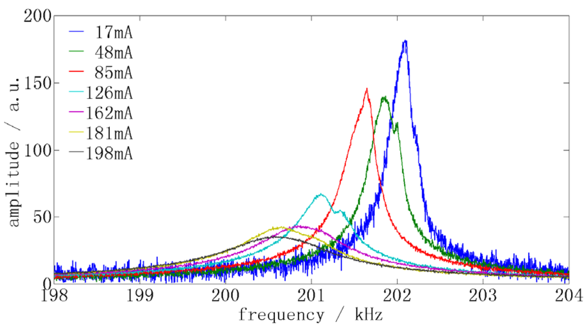


Figure 3: Beam spectra at different currents.

The buffer size as large as 500k samples provides Hz level frequency resolution. The tune shifts and betatron oscillation peak splitting during injection are easily observed. The information of beam impedance can be retrieved by fitting tune shifts with beam currents, shown in the Figure 4.

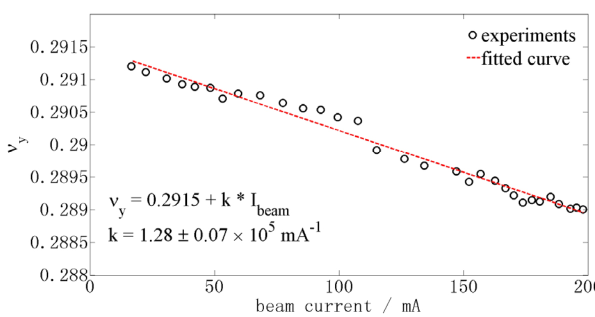


Figure 4: Betatron tune shifts during injection.

FA APPLICATION

Precise analyze of low frequency noise at TBT rate requires million samples of data. It will add too much CPU loading to processor to damage its reliability. Another choice is using fast application data (typical tens kHz) to do this job. In our case the data rate of FA block is configured to be 50 kHz and the buffer size is set to be 500k samples.

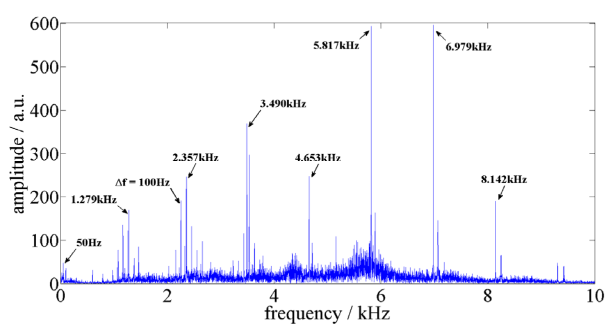


Figure 5: Orbit noise below 10 kHz.

Figure 5 shows the major horizontal orbit noise below 10 kHz. Low Q energy oscillation peak (5.8 kHz) and high Q electronics noise (1.279 kHz, 2.357 kHz, 3.490 kHz, and so on) coming from LLRF are easily observed.

More optimization work of RF system can be done based on this analyze.

When we focus on the orbit noise below 100 Hz, the more details can be found shown in Figure 6. The central frequency of major part of vertical orbit noise is about 5 Hz. The horizontal orbit noise consists three parts: 1~2 Hz, 20 ~ 30 Hz and 40 ~ 60 Hz. The horizontal and vertical ratio of power line noise and its second harmonic indicate that the noise is probably coupled from magnet power supplies but not BPM processor. The more orbit optimization work can be done based on this analyze.

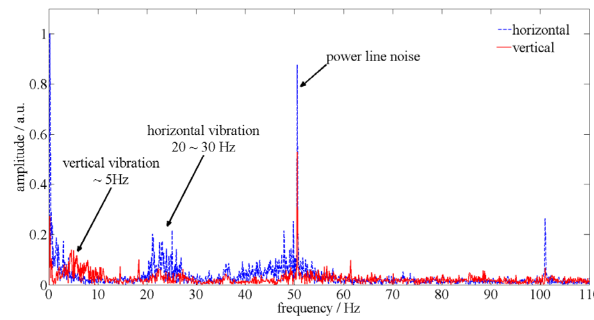


Figure 6: Orbit noise below 100 Hz.

SA APPLICATION

The basic functionality of SA block is providing close orbit information. With good calibration method and good linearity of ADC module the sum signal of four channels also can be used for beam current and lifetime measurement.

Figure 7 shows the orbit variation before, during and after injection captured by new DBPM processor. The horizontal orbit disturbances due to injection kicking during injection and the orbit changes due to close orbit correction after injection are clearly recorded.

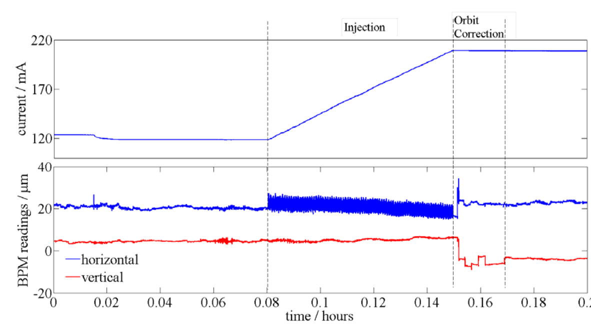


Figure 7: Measured orbit variation during injection stage.

The new processor shows very good linearity which makes measurement of beam current using sum signal possible.

Figure 8 shows the comparison of measured beam currents by DCCT and DBPM. The measurement error of DBPM due to nonlinearity is smaller than 1 mA in the range of 100 ~ 200 mA. This performance could be improved when high order calibration method applied.

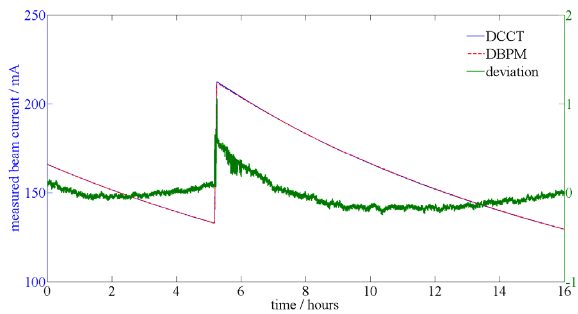


Figure 8: Comparison of measured beam currents by DCCT and DBPM.

Figure 9 shows the lifetime measurement result using DCCT and DBPM. It is obvious that the lifetime resolution of DCCT is much better than DBPM. But the traces of two measurements match together perfectly. The lifetime resolution of DBPM can be improved by involving more BPMs.

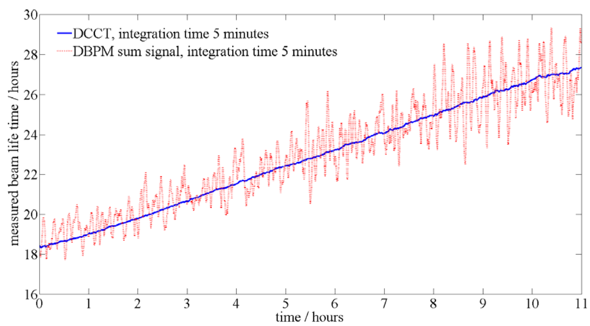
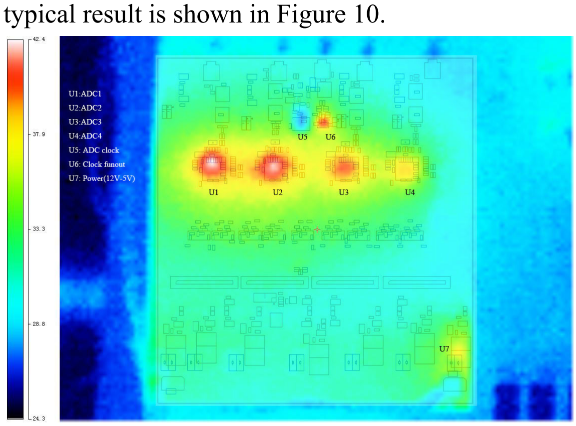


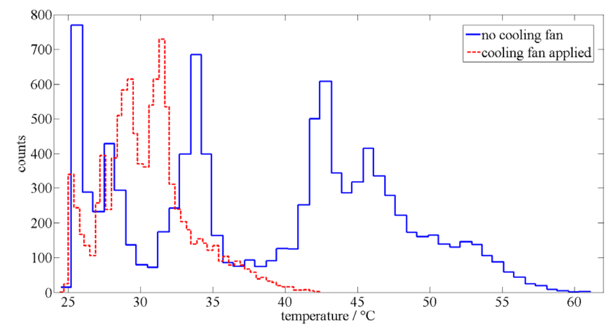
Figure 9: Beam lifetime measurement using DBPM sum signal.

THERMAL LOADING INVESTIGATION

Thermal loading is a critical issue for high performance instruments. High thermal loading, large thermal gradient or large thermal drift of circuit could crash the precision, reliability and long-term stability of DBPM processor. In order to collect enough information for the next technical prototype a thermal imager is used to investigate the thermal distribution of RF and ADC modules in the field. A typical result is shown in Figure 10.



(a) Spatial distribution of thermal loading.



(b) Histogram of thermal loading.

Figure 10: Thermal loading investigation of ADC module.

It is obvious that ADC chips are major thermal producers and cooling fan is definitely needed. After cooling fan applied the temperature of ADC chips decrease from 60 degree down to 42 degree and the average temperature of PCB board decreases from 43 degree down to 32 degree. More precise cooling design will be made and the new lower power ADC chips will be used in the next technical prototype based on this investigation.

CONCLUSTION

A prototype of new digital BPM processor has been evaluated online at SSRF storage ring. Major signal processing blocks including TBT, FA and SA have been tested. Thermal loadings of RF and ADC module were investigated. Evaluation results show that the functionality and performance are comparable with commercial products and satisfied the requirements of operation and machine study. Evaluation results confirmed the current design. The next technical prototype will be built soon.

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