DIGITAL BEAM POSITION MONITOR DEVELOPMENT AT NSRRC

C. H. Kuo, K. H. Hu, Demi Lee, Jenny Chen, C. J. Wang, K. T. Hsu
National Synchrotron Radiation Research Center, Hsinchu, Taiwan, R. O. C.

Abstract

A development of high precision of digital beam position monitor (DBPM) at NSRRC was performed. The implementation is emphasized on functionality and performance evaluation. The programmable nature of DBPM system is beneficial for multi-mode high precision beam diagnostics purposes. Sub-micron resolution is achieved for averaged beam position measurement. Medium resolution is obtain for turn-by-turn beam position measurement. Tune and other diagnostic measurements are also supported. The DBPM are seamless integrated with existed control system. Preliminary test results includes various aspects will be discussed and presented in this report.

INTRODUCTION

The digital receiver based beam position monitor (DBPM) is implemented [1, 2] in the NSRRC now. The purpose of this BPM electric system is used to evaluate and explore the potential and performance of the new technology for beam diagnostics application at the storage ring. The system composes a multi-channel coherent down-converter and a VME64x crate equips with multi quad-digital receivers boards (QDR). These new BPM can be achieved micron resolution in closed-orbit mode and high resolution in turn-by-turn mode.

The digital BPM electronics are commercial available products with product name DBPM2 [3]. The electronics consist of two parts, the first parts is 4 channels RF down converter that convert 500 MHz beam signal into intermediately frequency (20 MHz) coherently. Four IF signal are digitized and processed by a QDR board. The resolution of averaged beam position measurement can be better than one micron in RMS with 1 kHz bandwidth and achieve around 10 µm turn-by-turn resolution in 750 kHz bandwidth. The QDR consists of four symmetrical channels. The system block is shown in the figure 1. It consists of RF down convert, a band-pass filter, analog-to-digital converter (ADC), digital down converter (DDC), FIFO memory and FPGA is for the data acquisition and control purposes.

The ADC is based on AD6644/6645. It is used for the analog to digital conversion. This is a high speed, high performance, low power, and monolithic 14-bit analog-to-digital converter. All necessary functions, including track-and-hold and reference are included on chip to provide a complete conversion solution.

The programmable DDC is composed of synchronization, input, input level detector, carrier mixer, CIC decimating filter, half-band decimating filter, 255-tap programmable FIR filter, automatic gain control, Cartesian to polar converter.

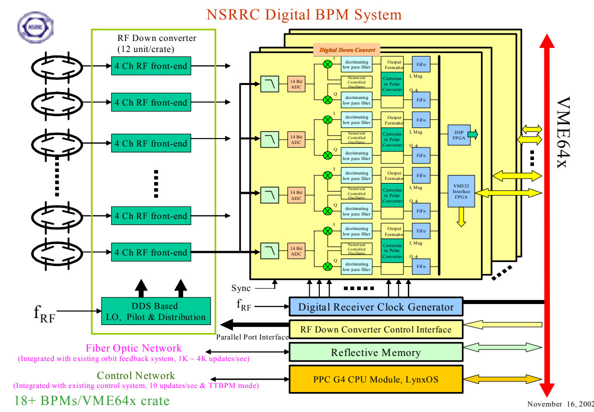

Figure 1: System block diagram of the digital BPM test-bed.

CONTROL SYSTEM INTERFACE

The control system interface is separated to two layers. The embedded layer is VME64x crate with PowerPC module running the real time operation system of LynxOS. The user interface layer is located at workstation/Unix and PC/Linux control console, support commercial software Matlab and LabVIEW. The VME host receives control parameters from user interface console by Ethernet. The control parameters include that change operation mode either turn-by-turn mode or closed orbit mode, adjust FIR filter coefficients and decimation factor of system. The data of DBPM is replied to user interface after receive software trigger from Ethernet. The software environment is shown in the figure 2. The DBPM is seamless integrated with the existing system.

There are two threads in the VME host. One is setting thread that handles all parameter control, such as turn-by-turn mode and close orbit mode control parameters update. Another is reading thread that handles control status response and data access of DBPM. All data and control parameter are collected in the share memory. The closed orbit data is sent to a dedicated BPM server node by reflective memory network. The update rate of closed orbit beam position is 1 kHz in the orbit feedback reflective memory network. The VME host of the BPM server down sampled the closed orbit data to 10 Hz and update to dynamic database in all control consoles.

The data of DBPM in turn-by-turn mode are directly served to client running on control console via control Ethernet. The input rate of DBPM is 49.965 MS/s. This clock is divided RF frequency ten directly. All DBPM work in phase coherently. The output rate is 2.49 MS/s after CIC, half-band and FIR filter. The CIC decimation factor is 10, half-band decimation factor is 2. BPM acquisition is started after accepts event from client. Position calculation is done after the FIFO of DBPM is full. The maximum depth of FIFO is 8192 long word in each channel. The maximum recording time is 3.2 milliseconds in the turn-by-turn mode.

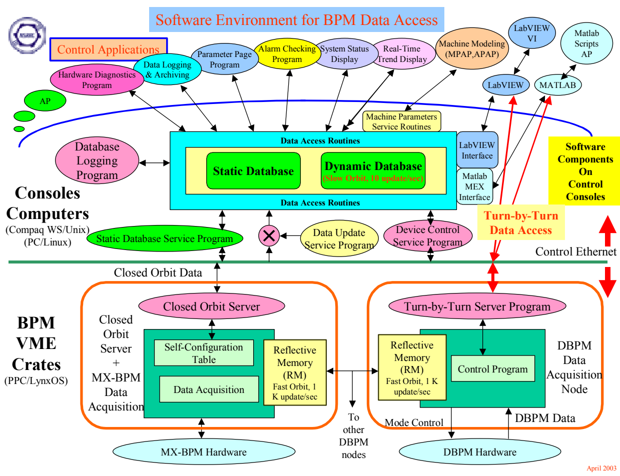

Figure 2: Software environment for BPM data access.

SYSTEM PERFORMANCE

To examine the closed orbit performance, short-term and long-term test in underway. The long-term stability can be achieved ~ μm level with 1 kHz output rate that is comparative with existing orbit feedback system. The resolution can be better after optimized the parameters of digital receiver.

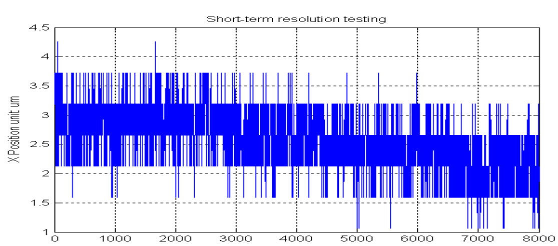

Figure 3: Short-term stability in the closed orbit mode with 1 kHz output rate.

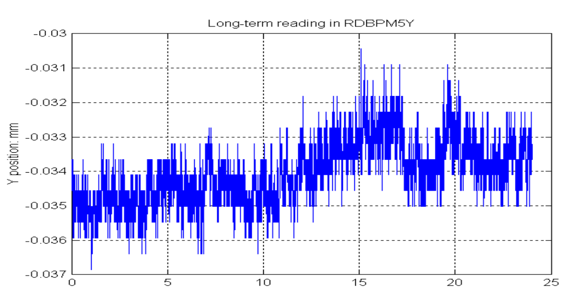

Figure 4: Long-term stability in the closed orbit mode with 1 kHz output rate.

The short-term standard deviation of BPM is 0.48 um. The operation condition is adjusted in the special test mode, output rate is 20 kHz. FIR filter bandwidth is 1 kHz in the last stage. The steady state drift is due to clear memory to empty in each access. In turn-by-turn mode, we need this mechanism. But we don't need clear memory in the close orbit mode, so drift problem isn't so evident. The status is shown in the figure 4.

The revolution frequency of the storage ring of NSRRC is 2.498 MHz. The turn-by-turn BPM electronics have 1.249 MHz bandwidth is essential in principle. However, the fractional tune of the storage ring is operated less than 0.33, bandwidth of 0.8 MHz is enough to support the measurement. The preliminary turn-by-turn parameters set achieves 0.8 MHz bandwidth (-3 dB) at this moment as shown in figure 5. The investigation is going how to increase bandwidth by optimize the parameters of digital receiver. Adopt data post processing to compensate the frequency response to increase the bandwidth is another alterative solution.

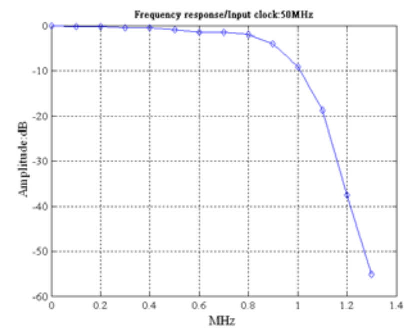

Figure 5: Bandwidth of DBPM system for turn-by-turn mode.

To demonstrate the functionality of the turn-by-turn mode, various testing have been done recently. Figure 6(a) presents the data of a BPM in frequency domain with horizontal kick. Betatron oscillation is clearly observed by the output of DBPM. Figure 6(b) shows the data of a BPM in frequency domain with vertical kick. Figure 7 shows a DBPM horizontal reading in the time domain of DBPM with ~ 1 mrad horizontal kick by an injection kicker, the horizontal betatron oscillation is excited. After two thousand turns, there is some coupling effect in the beam and then beam position is grown up.

The turn-by-turn beam position in for one DBPM is shown in the figure 8 when the RF gap voltage modulation is turn on. The RF gap voltage modulation is used to remedy the strong longitudinal coupled-bunch instability right now. The beam was excited by narrow band white noise, both horizontal and vertical betatron oscillation are excited. The top figure is the signal picked up by a single button. The prominent sinusoidal signal indicates the controlled energy oscillation by the RF gap voltage modulation. Turn-by-turn beam position is calculated by using four button signals. The horizontal position is ride on the 50 kHz of background that is shown in the middle figure. This background is due to un-calibration of the four button processing chain. Parallel processing electronics are insensitivity to the longitudinal instability in principle. The background can be minimized after applied proper calibration correction. Bottom figure is the vertical position shown clean betatron oscillation. The phase space measurement by two BPMs with horizontal phase advance near $\pi/2$ is shown in the figure 9. The difference color dots define various groups of turns.

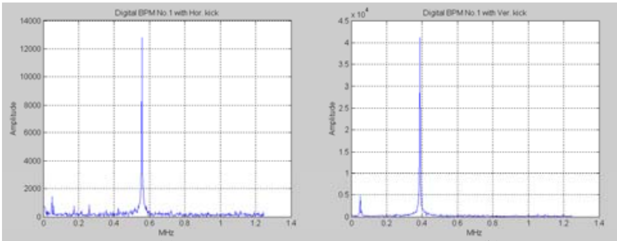

Figure 6: (a) The frequency domain of digital BPM with horizontal kick, (b) with vertical kick.

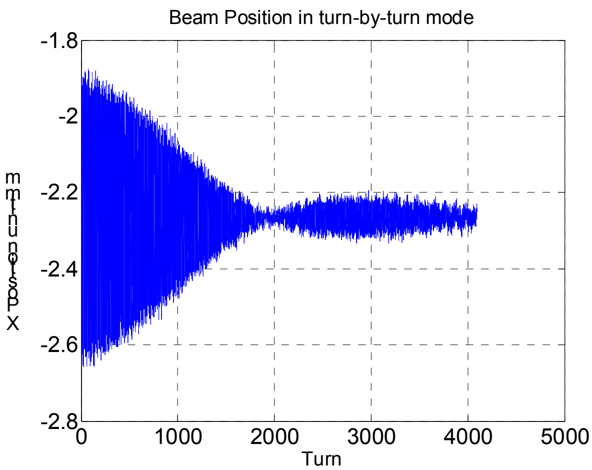

Figure 7: Damped horizontal betatron oscillation observed by a BPM.

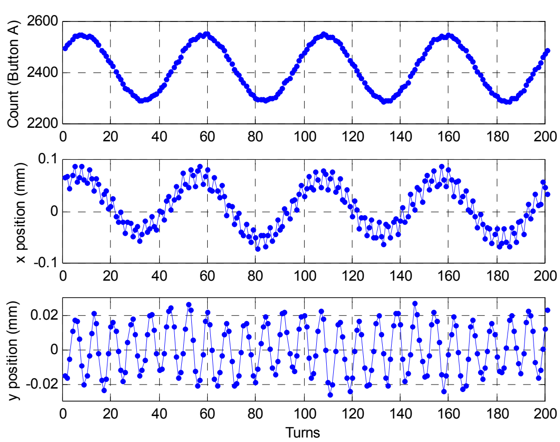

Figure 8: Turn-by-turn performance test of DBPM, shown that the turn-by-turn resolution is better than 10 μm. Upper: single button signal; Middle: un-calibrated horizontal position; Bottom: un-calibrated vertical position.

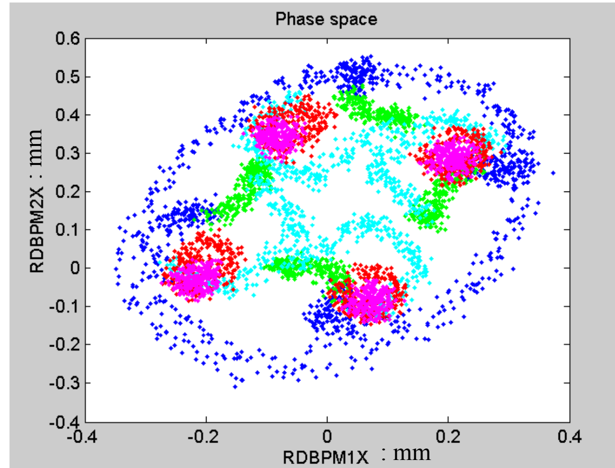

Figure 9: Phase space portrait near 4th order resonance, blue dots:1 to 1000 turns, green dots: 1001-2000, cyan dots:2001-3000, red dots:3001-4000, magenta dots: 4001-5000.

CONCLUSION

System integration and beam test is on going. The beam test results show that the system is working properly, but noise immunity is still necessary to improve. Although DBPM resolution is high in the wide bandwidth, it is still fatally interfered by the high frequency switching noise of the crate power supply due to alias effect. Remaining work includes integrating the system to join routine operation in closed orbit mode and develops better Matlab scripts to support various requirements for turn-by-turn mode. Solve interference come from the crate is also in investigation. Work out the calibration scheme is on-going. Integration small number of digital BPMs accompany with existing MX-BPM is short-term goal.

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[1] M. Dehler, et al., "Digital BPM System for the Swiss Light Source – First Operation Results", AIP Conference Proceedings 546, 572 (2000).

[2] V. Schlott, et al., "First Operational Experience with the Digital Beam Position Monitoring System for the Swiss Light Source", Procceding of EPAC 2000, Vienna, Austria, 1809 (2000).

[3] http://www.i-tech.si/products-dbpm2-p.html.