BPM INPUTS TO PHYSICS APPLICATIONS AT NSLS-II *

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Abstract

A new BPM (Beam Position Monitor) electronics is under development and in good progress at NSLS-II. This in-house BPM receiver with many new features is comparable to commercial solution. BPM data for fast orbit feedback (FOFB) is one of the most important physics applications. The procedure to use BPM for FOFB is introduced firstly. Then, different BPM data flows associated with different physics requirements and applications are discussed. And control implementation of BPM system for physics applications is presented.

INTRODUCTION

Generally a complete BPM system includes several components: pick-up (button, strip-line, etc.), electronics or receiver, control and high-level physics application software. Nowadays, most BPM-related R&D projects [1] [2] focus on its electronics. When people say "digital BPM", "RF BPM" or "BPM", they usually refer to BPM electronics. The new generation of digital BPM provides high resolution (sub-micron), superior long-term stability and flexible data flows.

Initially the commercial BPM Libera Brilliance was proposed [3] and evaluated [4] for NSLS-II. In-house BPM design started in August, 2009 [2]. Compared with Libera Brilliance, NSLS-II BPM has many new features: utilizing latest FPGA technology Virtex-6, no crossbar switching noise, easy programming by MatLab Simulink & System Generator for VHDL coding, embedded event timing receiver for better synchronization and global time-stamp, seamless FOFB integration since our Cell Controller [5] shares the DFE board of our BPM. And best of all, we'll get in-house expertise which is better for BPM system maintenance and future upgrade.

NSLS-II RF BPM is in good progress [6]. Most functionalities have been implemented as well as beam tested at ALS, LBNL. 200nm RMS resolution over 24-hour is achieved by housing the BPM receiver in thermally stabilized (+/- 0.1° C) rack.

PROCEDURE TO USE BPM FOR FOFB

Fast orbit feedback (FOFB) is one of the most important BPM applications. NSLS-II FOFB system architecture is shown in Fig. 1.

There will be at least 6 BPMs at each Cell (30 Cells in the Storage Ring). These local BPMs fast-acquisition data at 10 KHz output rate are collected by the Cell Controller and then distributed to neighbouring Cell Controllers. So, eventually each Cell Controller will get all BPMs data for global fast orbit feedback. In this architecture, the Cell Controller which shares the DFE board of our RF BPM is another important component. It acts as data concentrator, algorithm computation and communication link.

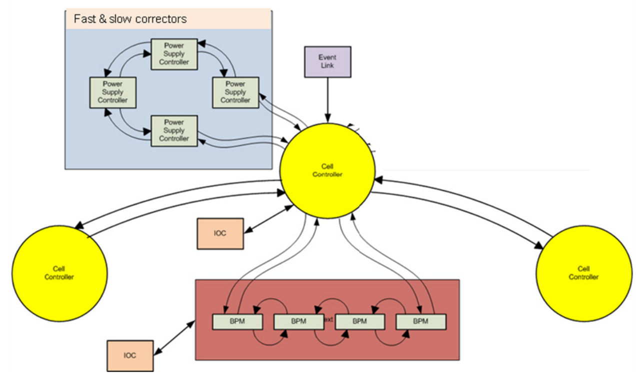

Figure 1: FOFB system architecture [5].

Beam Based Alignment (BBA)

The first step to use BPM data for FOFB is to perform beam based alignment (BBA). The purpose of BBA is to get BPM to quadrupole offsets and then use them for beam position calculations. Eq. 1 shows how we calculate the positions in our BPM electronics. X/Y are the horizontal and vertical positions, $K_{x/y}$ are the coefficients, $V_a \sim V_d$ are the measured BPM button signals and X_{offset}/Y_{offset} are the offsets measured by BBA. So, golden orbit is the offset in a sense.

$$X/Y = K_{x/y}\frac{(V_a+V_d)-(V_b+V_c)}{(V_a+V_b)+(V_c+V_d)} - X_{offset}/Y_{offset} \quad (1)$$

The BPM data used for BBA is slow-acquisition (SA) data at 10Hz. This SA data will be averaged to lower rate for higher resolution. 200nm RMS noise is the resolution requirement. There is no position drift issue during BBA because centring one quadrupole only takes short time.

NSLS-II Controls Group provides 10Hz BPM data as EPICS [7] PVs to high-level physics application and then physicists manipulate BPM data, slow correctors and quadrupoles to get the golden orbit. The BBA basic principle is steering beam to pass through the magnetic centre of individual quatrupole. BBA is time consuming and it's usually only performed during commissioning and start of each run.

Fig. 2 shows the layout of BPMs, quadrupoles and correctors for NSLS-II fast orbit feedback. And we'll use "Bowtie plot" (see Fig. 3) method for BBA data processing [8].

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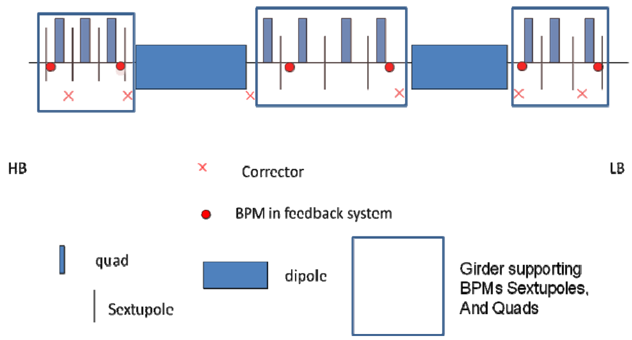

Figure 2: BPMs, Quads and correctors for FOFB [8].

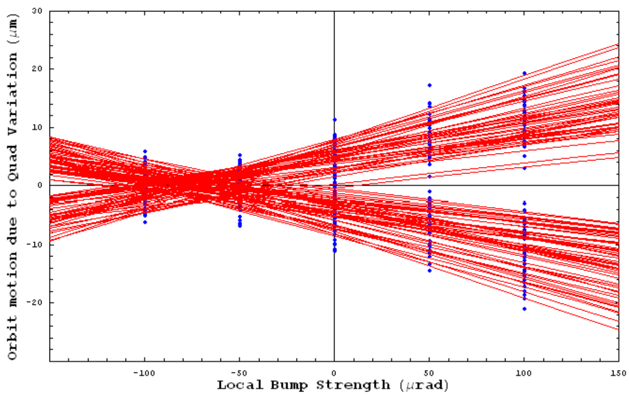

Figure 3: "Bowtie plot" method for BBA [8].

Response Matrix

The second step to use BPM for fast orbit feedback is to measure the response matrix (RM). This is for FOFB algorithm which is implemented inside Cell Controller FPGA. The orbit feedback computation is shown in Fig. 4.

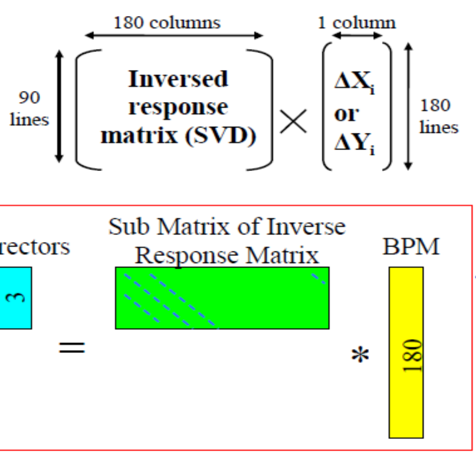

Figure 4: Orbit feedback computation [9].

The BPM data used for RM measurement is still SA data which has the same requirement as in BBA. But for this procedure, all BPMs data should be globally synchronized. Again, Controls Group provides the 10Hz BPM data and physicists manipulate BPM data and fast correctors.

Enable FOFB

Before we turn on fast orbit feedback, there are many things to do. Firstly we need to load our measurement data into BPM and Cell Controller FPGAs during initialization: BPM coefficients and BBA data into BPM FPGA; response matrix data into Cell Controller. Also, we should make sure all BPMs and Cell Controllers communicate well and the Storage Ring beam current should exceed pre-defined threshold (50mA). FOFB should be off during initial filling and then be enabled during top-off operation.

DC Shift

There is no slow orbit feedback at NSLS-II because our fast orbit feedback correction bandwidth goes from DC to 200 Hz. NSLS-II orbit feedback system is so named fast feedback with slow correctors. The reason we need slow correctors is that the fast correctors might saturate after long-term drift so that we should shift DC components from fast correctors to slow correctors. The rate of DC shift is flexible, i.e. from seconds to minutes.

Disable FOFB

We should turn off orbit feedback under the following circumstances:

- Initial filling the Ring from zero to full current;
- Machine physics study: BBA, RM, etc;
- BPM / Cell controller broken;
- Machine protection system (MPS) triggered;

But we might not dump the beam while disabling orbit feedback for the following reasons:

- The machine should be alive for a while even without FOFB;
- BPM interlock signal can be used to dump the beam;
- Other diagnostics such as DCCT, beam loss monitors, etc. might be used for MPS;

BPM & PHYSICS APPLICATIONS

The smallest beam size of NSLS-II is expected to be 3.1 um. So, the BPM system should provide position measurement resolution (RMS noise) at least 0.3um for long-term orbit drift which will be compensated by orbit feedback. Additionally, NSLS-II BPM system will provide turn-by-turn (TBT) data and ADC raw data for physics studies and BPM system debugging.

BPM is the key diagnostic instrument. NSLS-II RF BPM provides different data flows including 117MHz ADC raw data, 379 KHz TBT, 10 KHz fast acquisition (FA) and 10Hz SA for different usages.

ADC Raw Data

The first data flow is ADC raw data at ADC sampling frequency ~117MHz. This data path is useful for diagnostics and debugging. We used it to find a noise which is from power supply regulator.

10 ms (~ 3.8 K turns for NSLS-II Storage Ring) ADC raw data should be sufficient.

Turn-by-Turn Data

The second data flow is TBT data at revolution frequency ~380 KHz. Turn-by-Turn data are very useful and attractive to physicists. It will be used in many physics applications such as tunes, phase advance, injection damping, etc.

Here're some requirements for TBT data:

- Circular buffer: TBT data are continuously written into circular memory at revolution frequency. The arrival of a timing event stops the writing (freeze the buffer), then EPICS IOC reads out the buffered data;
- All BPMs TBT data should be synchronized: a counter for each turn;
- Resolution: 1 um is enough;
- 1-second/~380K samples TBT is sufficient for physics applications;

One of TBT BPM data applications is tunes measurements. The traditional solution is spectrum analyzer-based which is included in NSLS-II baseline design. Another solution is FFT the Turn-by-Turn data inside BPM FPGA. 0.01% frequency resolution requirement only needs 5K TBT samples so that this FFT computation can be easily handled by our RF BPM.

Fast Acquisition Data

The third data flow is FA data at ~10 KHz mainly for fast orbit feedback. Also we will use it for machine protection. And our BPM will provide spectral analysis by FFT. The requirements for FA data include globally synchronized all BPMs data and 0.4 um RMS noise.

Slow Acquisition Data

The fourth data flow is SA data at ~10 Hz. This data path is very useful and attractive to physicists. It will be used in many applications: beam based alignment, response matrix measurement, live orbit display, beam life-time measurement, etc. The requirements for SA data include globally synchronized and time-stamped, 0.2 um RMS noise.

BPM data flows associated with physics applications and requirements are summarized in Table 1.

Table 1: BPM Data & Physics Applications

Data Flow	Data Rate	Applications	Requirements
ADC	117 MHz	diagnostics, debugging	on demand; ~ 3.8K samples
TBT	378 kHz	tunes, phase advance, injection damping, etc.	on demand; 1 um resolution; ~ 380K samples; synchronization
FA	10 KHz	fast orbit feedback, machine protection	continuous; 0.4um resolution; synchronization
SA	10 Hz	beam-based alignment, response matrix, closed orbit, life-time	continuous; 0.2um resolution; synchronization

CONTROL IMPLEMENTATION

We'll have 2-layer architecture for BPM data usages and implementation. One is low-level control which makes BPM data as EPICS PVs. The other layer is high-level physics application which globally manipulates these PVs.

To simplify software design and provide better flexibility, we'll use external EPICS / Linux IOC for the BPM controls and data acquisition (ADC, TBT and SA) rather than embed IOC inside BPM receiver. Here're some basic EPICS implementations:

- ADC raw data: 4 waveform records with 1M (max.) elements each for 4-button (A,B,C,D) signals; ADC data are on-demand or upon timing event;
- TBT data: 5 waveform records with 1M (max.) elements each for 4-button plus a counter marking individual turn; another 4 waveforms (X,Y,S,Q) are calculated inside IOC from A,B,C,D; TBT data are on-demand or upon timing event;
- FA data: not available from EPICS IOC, they're streamed out form BPM FPGA;
- SA data: 5 longin records for A,B,C,D,S and 3 ai records for X,Y,Q; SA data are 10Hz continuously;
- Misc records for on-board diagnostics: temperature, BPM health, IOC CPU/memory usages, etc.

CONCLUSIONS

NSLS-II BPM receiver has excellent long-term resolution performance and provides flexible data flows which are enough for various physics applications.

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