THE DATA ACQUISITION SYSTEM OF BEAM POSITION MONITORS IN J-PARC MAIN RING

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Abstract

The Data Acquisition System of Beam Position Monitors(BPMs) in J-PARC Main Ring consists of 186 Linux-based Data Processing Circuits(BPMCs) and 12 EPICS IOCs. It is an important tool to see the COD and turn-by-turn (bunch-by-bunch) beam positions. This report describes the process of the data reconstruction which include how the various calibration constants are applied.

INTRODUCTION

In the J-PARC Main Ring, BPMs are located at the entrance of 93 Focusing Quadruple Magnets(QMs) and other 93 Defocusing QMs alternatively. For the Closed Orbit Distortion(COD) measurement it is required to cover from the beam injection to the beam extraction. We can take 3600 frames with 1ms time segment for single shot of precise measurement or 360 frames with 10ms time segment for continuous shots of normal operation. Where there are two normal operations, one is 3.52 sec cycle for fast extraction(FX) of neutrino experiment and another is 6.00 sec cycle for slow extraction(SX) of hadron experiment. For the turn-by-turn measurement we can see the bunch-by-bunch beam positions. It is used for mainly injection error and extraction orbit measurement. It can take up to 2322 turns for single shot or 6 turns for continuous shots.

OVERVIEW OF DATA FLOW

Each BPM sensor head [1] has two pairs (4 channels) of diagonal-cut-shaped pickups to detect horizontal and vertical beam positions respectively. The outputs of BPM's signals are connected to SMA-type feed-through and transferred with a few meters length 4 semi-rigid cables to the terminal assembled beside the QM. From the terminal, BPM's signals are transferred by a bundle of 100-400 meters length 4 coaxial cables to the electronics buildings (D1,D2,D3) on the ground then connected to BPMC. The signal digitized by BPMC is gathered to EPICS IOC via TCP/IP private network. IOC has another TCP/IP port which is connected to the upper stream of operator interface(OPI) at the central control room(CCR). Figure 1 shows the overview of BPM sensor head to OPI.

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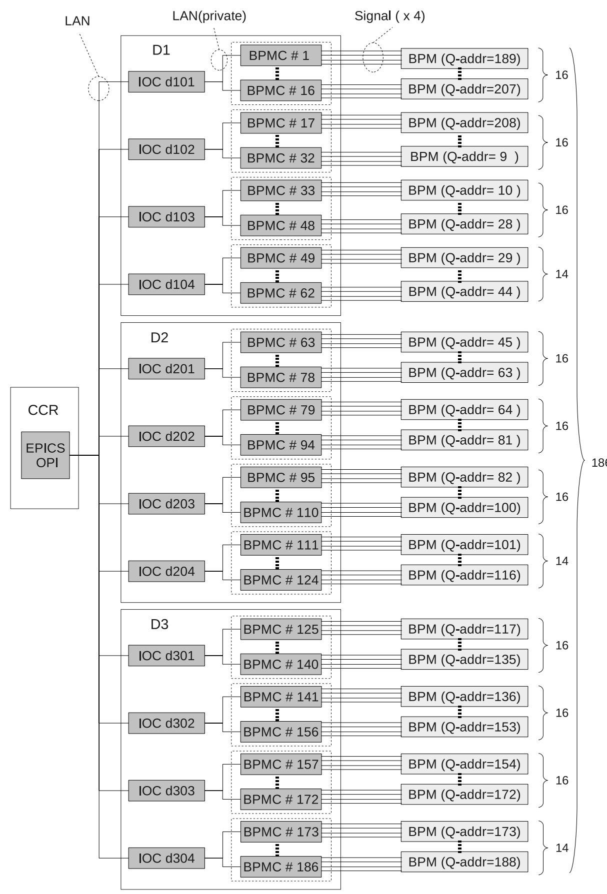

Figure 1: Overview from BPM to EPICS OPI.

BPMC

BPMC [2] is a device to process BPM's 4 signals. It has been developed by Mitsubishi Electric Co. and manufactured in 2003. The specification of BPMC is summarized in Table 1. Since number of particles per bunch changes from 10^{11}ppb to 10^{13}ppb in the beam commissioning phase, the gain of input signal is remotely adjusted to the ADC's dynamic range by changing amplifier / attenuator. When measuring COD, the embedded FFT chip is used to get the averaged amplitude of the signal in the 51.2μs time window. The frequency range to find FFT peak is decided by 2nd harmonic of RF frequency, F1=3.34MHz at injection to F2=3.44MHz at flat top. When measuring turn-by-turn position, digitized waveform are directly sent to EPICS IOC then bunch-by-bunch position is calculated.

EPICS IOC

An EPICS IOC (the Intel-based single-board computer with VME-bus) controls 16 or 14 BPMCs. The specification is summarized in Table 1. It is controlled BPMC's start/stop operation, changing parameters (record length, gain, trigger delay etc.). Also BPM's channel data is calculated to the horizontal and vertical positions. These sequences are written by State Notation Language (SNL) so called EPICS sequencer [3] which looks like C sentences. SNL can easily access to process variable(PV) with multi-thread support. BPMC's raw data(all parameters and waveforms) are saved on disk server in compressed binary format for every shot. Reconstructed position data are also saved in ROOT [4] format. Figure 2 shows data flow from BPM to IOC.

Table 1: BPMC and IOC specifications

BPMC Specification	
Signal Input	4ch (50 Ω, ±1.1V)
Amplifier	x1, x2, x5, x10
Attenuator	0dB, -10dB, -20dB, -30dB
Low Pass Filter	f_{cut} = 10MHz
Resolution/Sampling	14 bit / 80MHz
Max Record Length	1000000 samples/ch
FPGA	1024 sampling FFT
CPU Board	Geode GX1, 300MHz, 128MB RAM
Strage Memory	CF card(32MB), RAM disk
Data Bus	PCISA
OS	MontaVista Linux 2.1 (kernel 2.4.17)
IOC Specification	
CPU Board	Intel Pentium-M, 1.8GHz, 1GB RAM
Data Bus	VME
OS	Red Hat Linux 3.4.5 (kernel 2.6.9)
EPICS	R3.14

TRIGGER TIMING

BPMC is triggered by scheduled timing. For each electronics building(D1,D2,D3) there are VME trigger modules which receive 25Hz global clock(based on 12MHz master clock) from Central Control Equipment Room. The trigger module has look up tabel(LUT) which preset delay (~10ns to 2.79s) to send the TTL signals to various devices. There are 4 batches of injection timing(K1,K2,K3,K4) which are synchronized with RCS kicker timing (25Hz). For each batch, 2 bunches of beam are arrived, so as maximum 8 bunches of beams are injected to MR. When BPMC takes normal operation with COD mode or injection error measurement with turn-by-turn mode, the LUT is set to one of these 4 injection timing. In special case, to measure the FX orbit, the LUT is set to FX kicker timing.

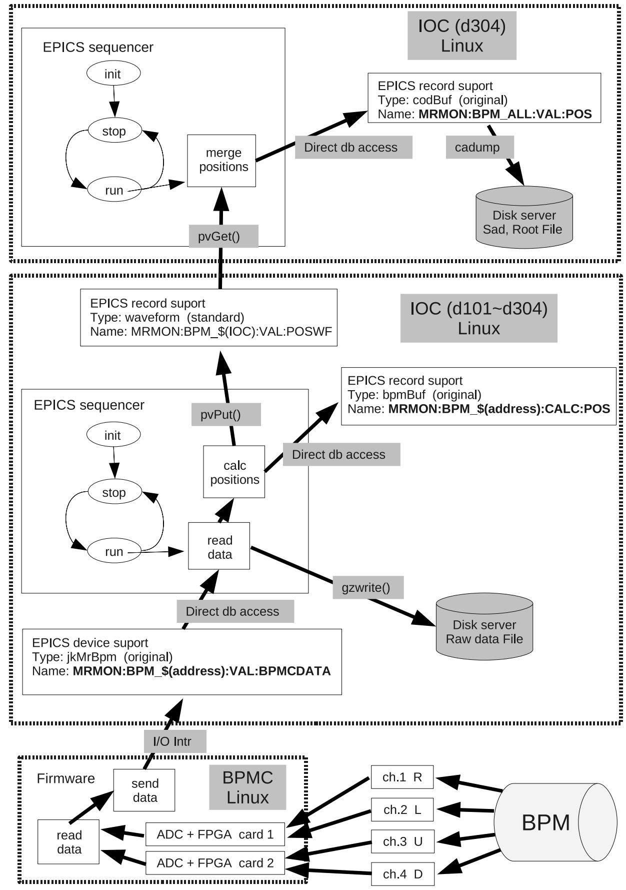

Figure 2: Data flow chart in BPMC and EPICS IOC.

CALIBRATION

The sensitivity coefficients(k_x, k_y) and offset and rotation errors of BPM sensor head are measured by wire-mapping method in the test bench at KEK [5]. The averaged value of k_x is 76.97(±0.25) and k_y is 76.86(±0.29) for normal size BPMs. We also measured the difference of 4 channels of BPMC's gain which depend on 5 patterns of amp and attenuator setting and 2 patterns of input signal's frequency (1.7MHz and 3.4MHz). This measurement has been done in the test bench at J-PARC site in 2007. Since diagonal-cut-shaped pickups have linear response the measured positions are calculated by the following formula[1],

$$\begin{bmatrix} x_m \\ y_m \end{bmatrix} = \begin{bmatrix} k_x(G_1R - G_2L)/(G_1R + G_2L) \\ k_y(G_3U - G_4D)/(G_3U + G_4D) \end{bmatrix} \qquad (1)$$

where R, L, U, D is voltage of right, left, upper and lower pickup of BPM, G_1, G_2, G_3, G_4 is correction factor of relative gain difference of BPMC's ch1-ch4.

Alignment errors of BPM sensor head from the center position of QM are measured using Laser Tracker during construction phase(2007-2008) [6]. The 1st beam based alignment (BBA) was done in June 2009 for one BPM as a trial. The 2nd BBA was done for 13 BPMs of horizontal positions in the SX section September 2009. The 3rd BBA

[1] we took left-handed system because beam revolves anti-clockwise.

was done for 3 BPMs of vertical positions in FX section April 2010. To take the BBA we set 3 patterns of local bump (-5, 0, 5 mm) at the corresponding BPM and set 5 patterns of the QM's compensate current ($-4, -2, 0, 2, 4$ A). At the moment changing these patterns was done manually so it takes an hour to take single set of BBA for one BPM's position. We are developing remote switching system and planning to do the whole set of BBA June 2010. After adapting all calibration factors the reconstructed beam position (x_b, y_b) is calculated by the following formula,

$$\begin{bmatrix} x_b \\ y_b \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \end{bmatrix} + \begin{bmatrix} x_0 + X_0 - X_{\mathrm{BBA}} \\ y_0 + Y_0 - Y_{\mathrm{BBA}} \end{bmatrix} + \begin{bmatrix} (\varphi_z - \theta_x)(y_m + y_0) + \varphi_z Y_0 \\ (\theta_y - \varphi_z)(x_m + x_0) - \varphi_z X_0 \end{bmatrix} \quad (2)$$

where, $x_0, y_0, \theta_x, \theta_y$ are offset and rotation errors measured by wire mapping, X_0, Y_0, φ_z are BPM's alignment offset and rotation errors against QM, $X_{\mathrm{BBA}}, Y_{\mathrm{BBA}}$ are offset by BBA. To reduce Eq.(2) the following approximations are adapted,

$$\begin{array}{rcll} (\sin\varphi_i)(\sin\varphi_j) & \simeq & 0, & (i,j = x,y,z), \\ \sin\theta_i & \simeq & \theta_i, & (i = x,y), \\ \cos\theta_i & \simeq & 1, & (i = x,y), \\ \sin\varphi_i & \simeq & \varphi_i, & (i = x,y,z), \\ \cos\varphi_i & \simeq & 1, & (i = x,y,z), \\ 1 - \theta_i\varphi_z & \simeq & 1, & (i = x,y) \end{array} \quad (3)$$

EXAMPLE OF BEAM DATA

For the operator interface we use edm(Extensive Display Manager) which is one of useful EPICS GUIs. Figure 3 shows waveform of BPM's pickup voltage in 2400 sampling(30μs) time window. Left graphs are ch1(R) and ch2(L) signals and right ones are ch3(U) and ch4(D). The upper graph shows peak-to-peak amplitude of beam bunch, middle one is time domain waveform and lower one is frequency domain waveform. In this example, we can see two bunches of beams at K2 injection batch.

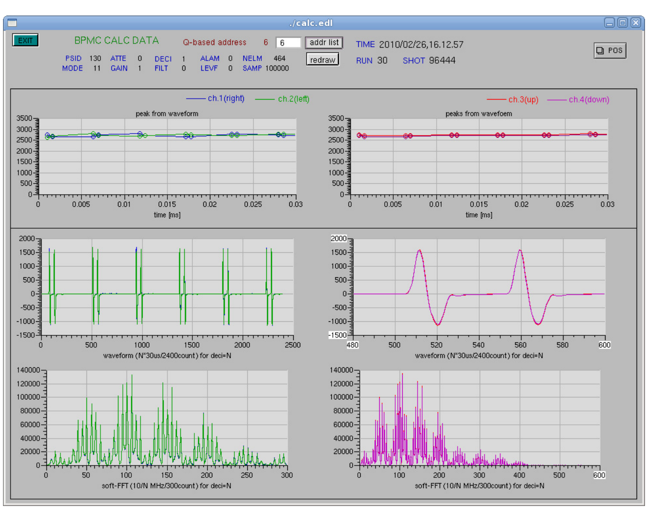

Figure 3: Waveform of MR 2 bunch beam.

Figure 4 shows 200 turns of front bunch positions at K2 injection batch. The betatron oscillation is fitted to sinusoidal curve for each 10 turns and got result that the injection error is 3.37mm. Also the decimals of horizontal betatron tune is determined to 0.408 ± 0.005 by FFT peak search. In this example, the injection kicker and septum was not optimized yet so the injection error is relatively larger than normal value(~ 0.5mm).

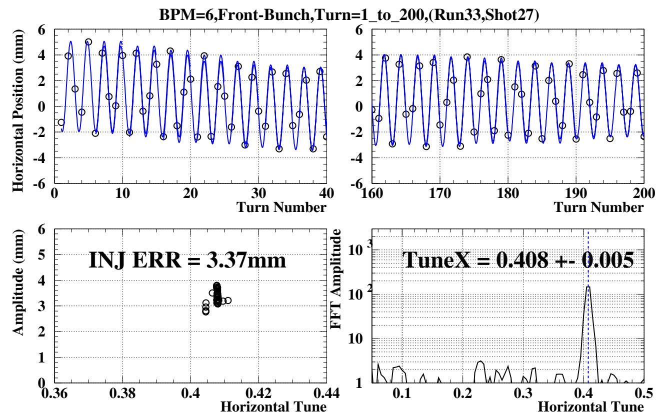

Figure 4: Betatron oscillation and tune of injection beam.

SUMMARY

MR beam commissioning started from April 2008 and the DAQ of BPM has been performing well as a beam diagnostic tool. We are planning to do a full set of BBA next June to get more accurate COD.

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