PERFORMANCE OF THE MAIN RING BPM DURING THE BEAM COMMISSIONING AT J-PARC

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Abstract

Experiences of operating BPM's during beam commissioning at the J-PARC MR are reported. The subjects are: (1) bug report, statistics and especially the effect of a beam duct step, (2) position resolution estimation, (3) test of beam based alignment.

INTRODUCTION

J-PARC Main Ring (MR) has started the beam commissioning in May 2008[1]. Acceleration upto 30 GeV, slow extraction to the hadron beam line and fast extraction to the neutrino beam line were achieved by April 2009. Beam position monitors (BPM's) have been efficiently utilized for beam commissioning. Beam intensity has been increased from 4x10^{11} at the initial commissioning to 7x10^{13} protons per pulse in this FY (Fig. 1). Beam parameters are listed in Table 1. BPM's are installed in the 3-50 BT, MR and injection- and abort-beam dump lines. The numbers and apertures of those BPM's are summarized in Table 2.

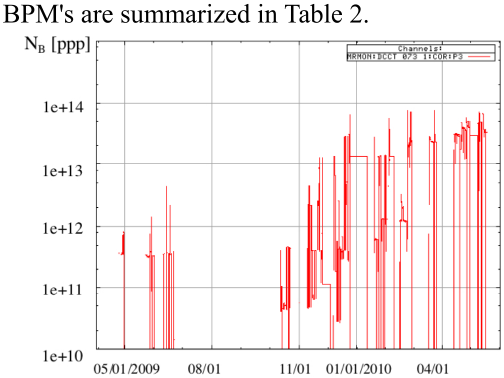

Figure 1: MR beam intensity since FY2009.

Table 1: Beam Parameters

	FY 2008	Design	
Proton number	~4x10^{11}	4x10^{13}	p per bunch
Emittance (3 GeV)	~15	54	π mmmrad
Number of bunches	1	8	
Peak current	0.5 - 6	220	A
Ave. current	0.12 -0.14	12-14	A
Bunch width	40 - 70		ns
β	0.9712 - 0.9998		
f_{rev}	186 - 191		kHz
Revolution period	5.38 - 5.24		μs
RF frequency	1.67 - 1.72		MHz

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BPM OPERATION

The 3-50 BT, injection dump and abort dump BPM's observe one-pass beams, while MR BPM's circulating beams[2]. One-pass BPM's are processed with time-domain data analysis, while MR BPM's processed with fast Fourier transformation in addition.

The initial stage of beam commissioning took full use of these BPM's. Deeper understanding of machine parameters, injection beam dump has become less useful. Signal processing circuits for injection beam dump BPM's are converted for MR BPM's to measure transverse dipole mismatches of injected beams into MR. The signals of 3-50BT BPM's[3] and abort dump BPM's are processed with digital oscilloscopes (Agilent 6014L) and analyzed at OPI.

Although the diagonal-cut BPM's had been originally designed with external capacitors to obtain wider frequency response in monopole mode, it was decided to operate without external capacitors because it was expected that the initial beam may be too week to observe with enough signal to noise (SN) ratio. The signal into processing circuit, therefore, would become too large. External attenuators (8-10dB) were attached on the original circuits in June 2009. They can withstand up to ~100kW beam. For higher beam power the new switchable attenuators are in preparation. The stripline BPM's are processed with the digital oscilloscopes with a long memory (Lecroy WavePro715Zi) and used for examining dipole oscillations within a bunch.

Table 2: BPM's in 3-50BT, MR and beam dumps

monitor	#	size
3-50 BT		
60-degree parallel cut	14	ϕ200, ϕ230
MR		
Diagonal cut	186	ϕ130,ϕ134,ϕ165,ϕ200,ϕ257, 140x302
Stripline (loop coupler)	2	ϕ134
Injection dump BT	2	ϕ200, ϕ320
Abort dump BT	2	ϕ257

Malfunctions and abnormal behavior

Malfunctions occured at the initial stage are summarized in Table 3. Even after taking measures against those malfunctions, some BPM's work incorrectly as the beam intensity increases. One of the source was the charge-up of a BPM electrode. Figure 2 shows the observed signal of the electrode with direct connection to a low pass filter (720 Hz) + 1 MΩ load of oscilloscope. The beam power was ~100 kW equivalent. A beam loss and a vacuum pressure rise (10^{-3} Pa) at the BPM location were observed with only one shot. It is suspected that an electron cloud is growing up.

Table 3: Malfunctions during the initial commissioning

Errors	#	Detections	Measures
interchanged connection	7	unphysical orbit	proper connection
trigger setting	2	unphysical orbit	correct value
bad contact	12	abnormal waveform	re-connection, parts replacement
alien substance in vacuum	1	abnormal waveform	remove the substance
steps of the beam duct	2	comparison to neighbour BPM's	bypass insert, correction

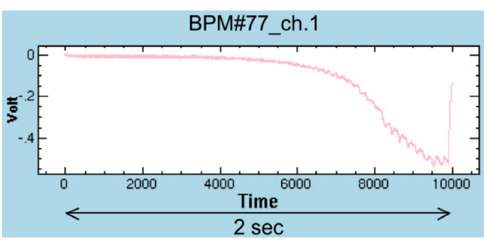


Figure 2: Charge-up of the BPM electrode.

Effect of a Beam Pipe Step

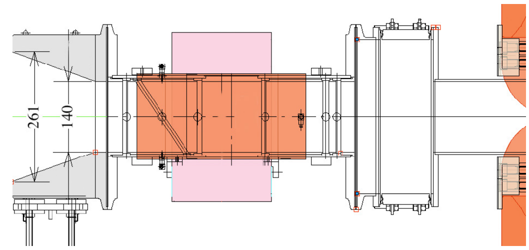
In the fast beam extraction area, two big steps between the beam pipe and BPM were overlooked. The structures are as Fig. 3.

In order to understand the error source, a model calculation was executed using a simple cylindrical step (Figure 3). Assuming a beam runs on the z-axis, induced charges (electric fields perpendicular to the pipe wall) were calculated applying the field matching technique between the region I and II [4]. The charges gathered by the electrodes are approximately equal to the surface charges on the triangular area of the pipe surface shown with the dashed line in Fig. 4. Taking into account the induced surface charge as shown in Fig. 5, larger total charges on electrode B is obtained than the one of A, even though the beam is on axis. This yields the erroneous offset.

In practice comparing the position data of neighbouring BPM's, the following calibration constant were obtained:

BPM address	offset	position sensitivity
154	6.05 mm	0.977
155	-8.83 mm	1.080

To remove the error source, a wall current bypass was inserted in the step next to the BPM 154 in Sep. 2009. As for the BPM 155 the above correction has been used because no insertion is possible for this geometry.



(a) BPM and beam pipe at address 154.

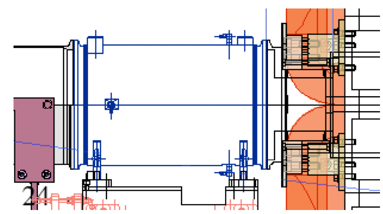

(b) BPM and beam pipe at address 155.

Figure 3: Beam Pipe Steps in MR.

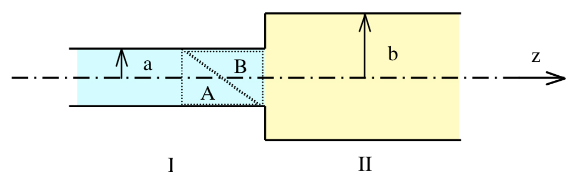


Figure 4: Step of the cylindrical pipe.

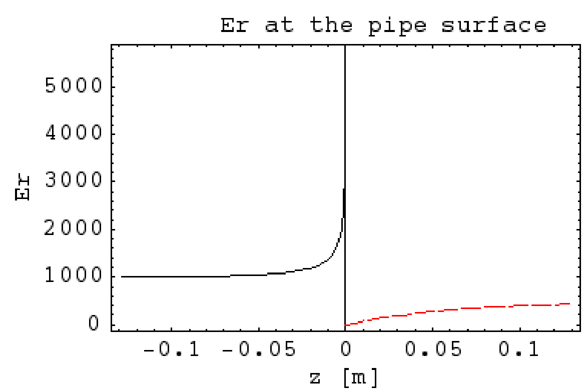


Figure 5: Induced charge on the beam pipe along the longitudinal direction (z).

RESOLUTIONS AND OFFSETS

The typical position resolution was measured for the "COD mode"[5] at the beam intensity of $4x10^{11}$ protons per bunch (ppb) and single bunch. The rms of 1000 data for all BPM's is plotted along the ring in Fig. 6. Green and red lines are the rms of horizontal and vertical positions, respectively. These rms values contain the effects of magnet ripples and beam related oscillations. Threefold symmetry of the horizontal case, repeating 6 peaks three times along the ring, is due to the momentum dispersion. The temporal evolution of the position at the rms peaks has the frequency component of the synchrotron tune. The other threefold symmetry of the vertical case is due to the SN ratio variation. The cables are distributed from the three symmetrically located equipment buildings, to the BPM locations along the ring. The cable length variation, therefore, has threefold symmetry. The signal attenuation in the cables, therefore, has the similar dependence of the cable length variation.

Averaging 1000 data yields the positions with the rms less than 30 μm.

All lattice quadrupoles are equiped with the auxiliary windings. Preparation of remote-controlled power supplies for BBA is in progress. With a tentative setup, experiments were performed three times: address 89 (horizontal) in Jun. 2009 (Fig. 7), slow extraction area (address 73 - 87) in Oct. 2009 and fast extraction area (address 153, 154, 155) in Apr. 2010. The first and second were with the same beam condition ($4x10^{11}$ ppb and single bunch) and the rms of offset values were 60-160 μm. Third trial was done with the beam intensity $4x10^{11}$ ppb and 6 bunches. This realizes a better rms such as 30-80 μm.

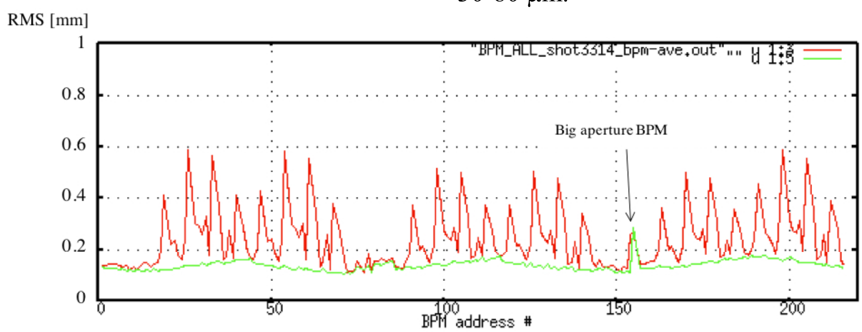
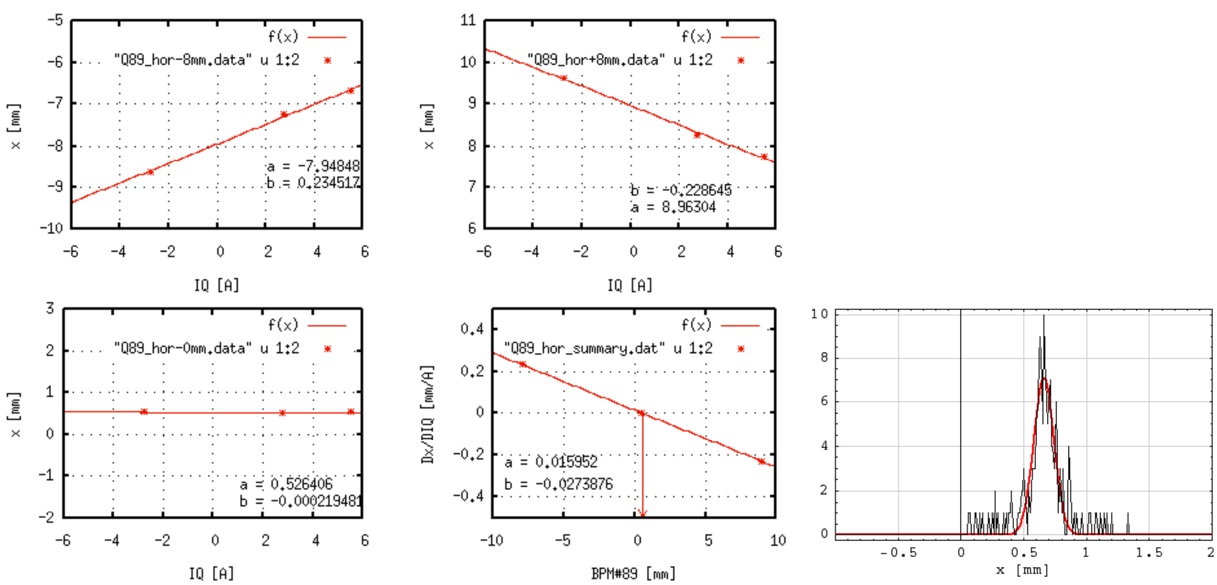


Figure 6: RMS of the 1000 position data measured during 3GeV injection flat bottom.



(a) (b)

Figure 7: Result of the Beam Based Alignment. (a) analysed using BPM89 only, (b) using all BPM's.

SUMMARY

- Initial malfunctions of BPM's are detected, analysed and measures are taken for each case.
- Position resolutions are estimated for "COD mode" of the MR BPM's and the offsets are partly determined with the precision of 30 -160 μm (rms) using BBA.

REFERENCES

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