

THE BEAM POSITION MONITOR SYSTEM FOR THE J-PARC RCS

N. Hayashi[#], S. Hiroki, R. Saeki, R. Toyokawa[†], K. Yamamoto, JAEA/J-PARC, Ibaraki-ken, Japan
D. Arakawa, S. Hiramatsu, S. Lee, K. Satou, M. Tejima, T. Toyama, KEK, Ibaraki-Ken, Japan

Abstract

The Beam Position Monitor (BPM) system of the J-PARC RCS has been fabricated, installed and operated successfully during the beam commissioning. There are 54 BPMs around the ring and most of them are placed inside steering magnets. The BPM is electro static type and it has four electrodes. A pair of electrode gives a linear response with diagonal cut shape and they were calibrated before their installation. The signal processing unit, which is equipped with 14-bit 40MSPS ADC and 600MHz DSP, has been developed for the system. In order to measure small signals, especially during the initial phase of the commissioning, a careful design also done for cabling. The paper presents the current performance of the system.

INTRODUCTION

The BPM (Beam Position Monitor) system is the most important device in the beam diagnostic system. In the J-PARC RCS [1], its BPM system has been developed, installed and has begun to be operated since the RCS commissioning [2]. This paper describes this BPM system, especially, calibration of the sensor head, installation, electronics, and its control system.

There are 54 BPM sensor heads around the ring for COD measurements. Every half-cell, BPM is located in front of a quadrupole magnet or behind of that. Since space is quite limited, most of them are inside steering magnets. They are connected to signal processing unit via 120~160m cable. The signal processor consists of analogue part, digitization part and on-line position calculation units. It can calculate both COD and turn-by-turn position.

SENSOR HEAD

The sensor head is an electro-static type and made of titanium. Various design features are tested with a proto-type [3]. The electrode is cutting with diagonal shape in order to have a linear response not only in the central region. According to the physical aperture requirement, there are three sizes of normal BPM, $\phi 257$, 297 and 377. The length along the beam axis is 360mm including bellows of about 120mm. Exceptionally, two BPM around the injection area are very large to cover the injection and the H0 dump orbit. Their electrodes are square shape and the size is 504 x 212mm and 470 x 300mm, horizontal x vertical gap respectively. The outer vacuum chamber is 400mm long and cylindrical, but it is too large to have an electrode. So, we put the outer

electrode inside the chamber. A gap between outer and inner electrode is 2mm and its length is 112mm. It is not exactly to diagonal cut shape, but it is similar. In order to gain even more horizontal physical aperture, the centre of these BPM and vacuum chambers is shifted with 95mm from QM centre (circulation orbit centre).

Its capacitance is increased from proto-type, because a number of support ceramics bar increases from three to seven. They are about 300, 330 and 380pF for each size. Even they differ from the average, balance between paired electrodes is important and it is below 1%. Two larger BPM is more difficult but they are within 5%.

Calibration

After fabrication, all sensor heads are calibrated. The sensor head is placed on the stage precisely. A centre wire and the head position is aligned by an auto level and a theodolite. A signal source of a network analyzer (ZVT8; Rode & Schwarz) is amplified (33dB) and feed to the centred wire and pickup the by two ports of the network analyzer. The wire is moved by a stepper motor with 20mm pitch. Since the electrode pair is 45 degree rotated, the wire is moved along this direction. Measured frequency region is from 150kHz to 10MHz with 21points. Mapping range (radius) is within 100mm for $\phi 257$, 120mm for $\phi 297$ and 160mm for $\phi 377$. Numbers of measured points become 101, 129 and 219, respectively. The network analyzer has three ports, while the four pick-ups and one source port is necessary. So, the wire scanning was performed two times for one head. A LabVIEW program controls the motor and the network analyzer measurement. The obtained data is fitted by a linear function and coefficient is calculated at 1.22MHz. They show quite good linearity shown in Fig.1.

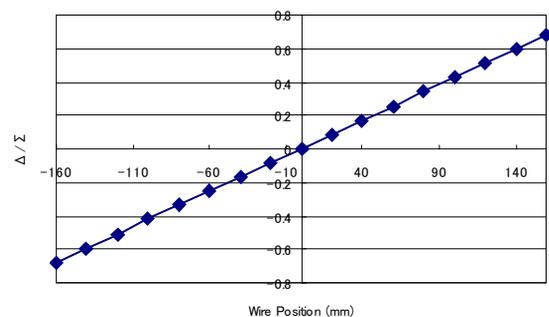


Figure 1: Sensor head calibration by wire.

[#]naoki.hayashi@j-parc.jp

[†]Present affiliation: Nippon Advanced Technology Co.,Ltd.

INSTALLATION

An installation procedure is as follows. Firstly, the upper iron of a steering magnet is removed and a BPM is placed. The BPM is clamped together with the ceramics duct (QM side) and connected to the other side. Because we don't want to push any stresses to the ceramics duct, an alignment procedure, precise position adjustment, was not done. Instead of the alignment, we measured the sensor head position by a laser tracker with respect to the closest QM. Results show that most of them are placed within 0.5mm and few have larger than 2 mm accuracy.

In order to have a flat frequency response around 1MHz, the PEEK cable from the sensor head is connected to impedance matching transformers. They are besides the steering magnet. To isolate the sensor head ground, the transformer is in double shield boxes.

Four PEEK cables with shield transfer the signal to substitute tunnel under the main machine tunnel through the metal pipe. It is good for mechanical protection and noise shielding. From the substitute tunnel to the 1st floor electronics room, four coaxial cables with shielding is used.

SIGNAL PROCESSING

The BPM signal processing units are designed to adapt wide band. So, it is capable to do continuous measurement of COD with 25Hz (without missing any pulse) and it is also able to take turn-by-turn measurement (including waveform). The unit is a VME three width and six units are plugged into the 20 slots sub-rack. A local board CPU equipped with Ethernet and a shared memory (reflective memory) board controls these six units. There are three local electronics rooms in the RCS building. Each room has 3 BPM VME sub-racks, and it becomes 54 units for all BPM.

Analogue Circuit

The purpose of the analogue circuit is to adjust outputs to match ADC input range between -1.1 to 1.1V. It has also monitor outputs for debugging or checking by an oscilloscope. The signal circuit has various amplification ranges, x1, x2, x5, x10 and their combinations. It has also step attenuators, -10dB, -20dB and -30dB. The maximum voltage is expected to be over 20Volts. In front of the circuit, larger heat capacity chip resistors were chosen. There is an anti-aliasing LPF, 6th order butter-worth with cut-off 5MHz.

Digital Circuit

It has four 14-bit 40MS/s ADC, AD9244, and 600MHz DSP for FFT of 1k, 2k or 4k sample points. 4k points correspond to about 100µsec time and about 50 turns around injection period.

After FFT for each channel, the peak value within a certain range is detected and the position is calculated with simple formula. Assuming peak values for each

channels are V_a , V_b , V_c and V_d , horizontal and vertical positions x , y will be

$$u = a_1 \frac{V_a - V_b}{V_a + V_b} + b_1, \quad v = a_2 \frac{V_c - V_d}{V_c + V_d} + b_2$$

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix}$$

Coefficients, a_1 , a_2 , b_1 , b_2 and θ , are determined from the calibration table and position measurement after installation. Rotation is resumed at this process. In COD mode, 20 consecutive measurements are processed with interval of 1 msec.

Noise floor with different gain are presented in Fig.2. Signal to Noise ratio between x10 and x100 are same. But from x1 to x10, S/N ratio is improved. So, gain x10 is standard with the Linac current of 5mA peak.

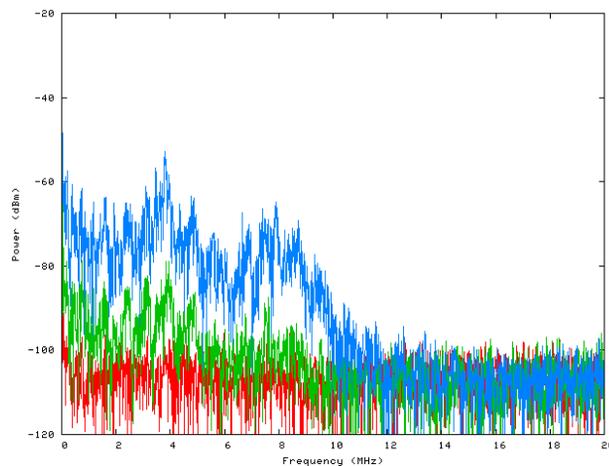


Figure 2: Noise floor with different gain. Red is x1, green is x10 and blue is x100. Vertical axis is power integration of 10kHz binning.

Control System

Each VME/CPU has reflective memory and it is connected through fiber optic cable. They and some PC shares 128MB memory space. The specific area is kept for several hundred shots of COD data. Every time new data are available, it is overwritten on the oldest data. It is used as ring buffer. Long waveform data or single pass data also put in. In the heaviest case, all units run as waveform mode, and 8Mbytes per channels becomes more than 400Mbytes. It takes about four minutes to dump on the HDD. Pulse-to-pulse time information is also distributed through this reflective memory and it is embedded into the BPM data. Control commands or setting parameters are also passed through this shared memory space. Server PC converts these data into the EPICS records for high level applications. The technical detail is described in ref. [4].

The system can be booted up as stand alone mode, if the reflective memory is not available. It is useful for the debugging phase.

PERFORMANCE WITH BEAM

Before amplification, the signal height of about 0.5mV is shown for 5mA of Linac beam current. Figure 3 shows the injection behaviour with 100 μ sec injection time with one bunch mode at the RCS. One can count more than 40 intermediate pulses, and every turn the signal grows up. FFT plot is shown in Fig4.

When the higher Linac current is available, only one intermediate pulse is injected. The signal is quite visible and lots of study is performed with this condition.

The COD data is processed and they are used COD correction (Fig.6) or other beam optics measurements.

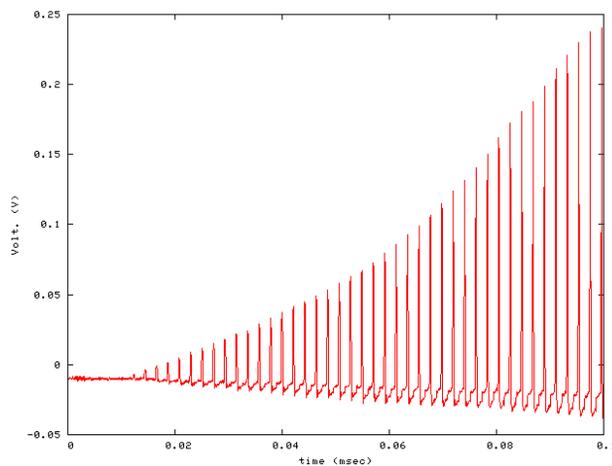


Figure 3: Time domain signal at injection.

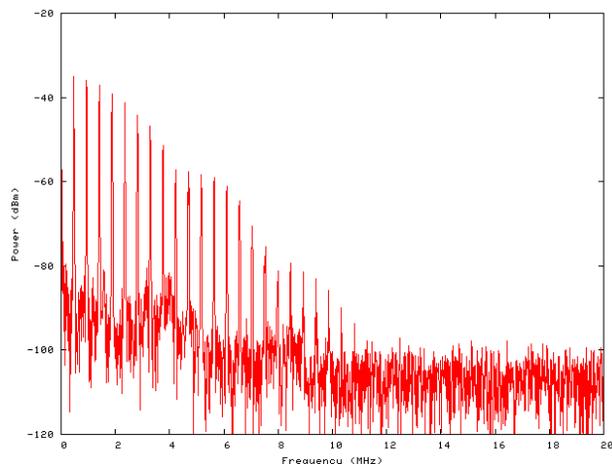


Figure 4: FFT plot of Fig.2 data.

SUMMARY

The BPM system for J-PARC RCS is presented. A good linear response is confirmed by calibration results. Reflective memory is useful to update rapidly changed

data and also for big data. Low noise system is demonstrated without or with the beam conditions.

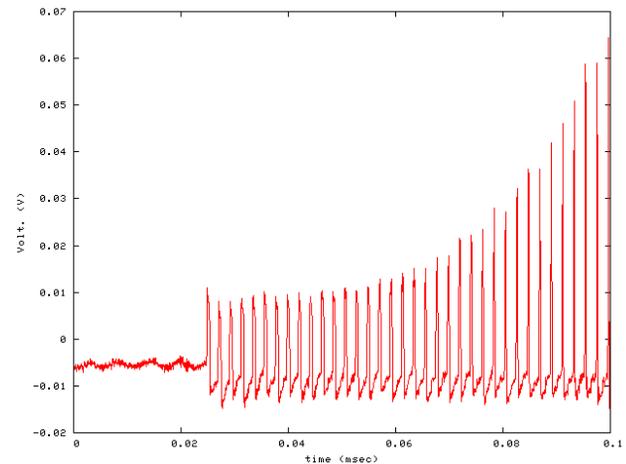


Figure 5: One intermediate pulse injection.

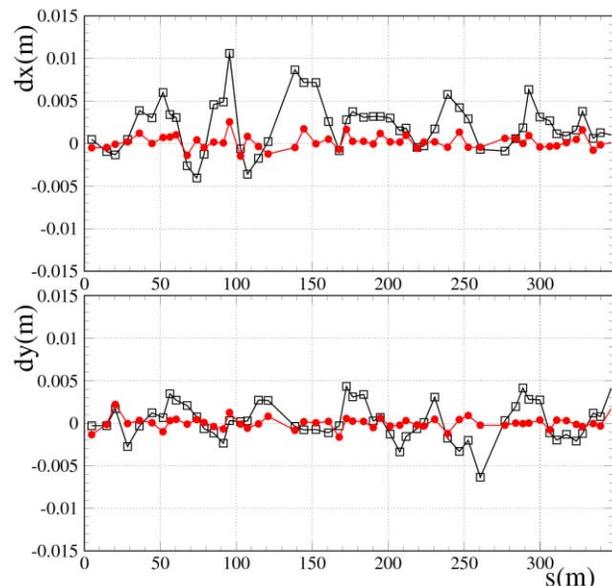


Figure 6: Closed orbit at injection energy. Black square is before correction and red solid square is after COD correction. Few mal function BPM data are not plotted.

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