BEAM POSITION MONITOR FOR THE J-PARC MAIN RING SYNCHROTRON

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Abstract

A BPM system has been developed for the J-PARC Main Ring Synchrotron. A diagonal-cut 'electrostatic' pick-up and a processing circuit with an analog amplifier, attenuator, filter and ADC are adopted. The system expects no active devices in the tunnel to avoid radiation damage. The system aims at a position accuracy of ±0.1 mm. The test using whole system except a cable at the KEK-PS shows good system performance with the position resolution better than ±20 μm. The position accuracy will be attained with careful installation and beam based calibration.

INTRODUCTION

J-PARC 50 GeV Main Ring Synchrotron will feed 3.3×10^{14} protons per pulse (typically in 3.6 s), corresponding to an average current of 12.4 - 12.8 A and a peak current of 41.3 - 220 A as shown in Table 1[1]. Main features of this machine are: (1) high intensity, (2) main frequency components are localized less than a few 10 MHz, (3) a beam size is large both in transverse and longitudinal. To fit these characteristics the following design principle is adopted: (a) electrostatic pickup with diagonal-cut cylinder for linear response to the position, (b) no active devices (semiconductors) will be installed in the tunnel.

Signal processing is performed using a 14 bit - 80 MSPS ADC with 10 MHz LPF. The data acquisition and module control will be accomplished using a control software tool-kit, EPICS, in principle. Large data will be exceptionally handled with ftp [2]. The dynamic range of the system should meet the following conditions: (1) initial beam commissioning will be done with 1/100 of the design intensity [3], (2) the peak beam current is expected as 41 - 220 A.

The precise position measurements and COD correction is crucial to prevent beam losses at the injection flat

Table 1: Parameters of the 50 GeV MR

Parameter		Unit
Peak beam current	41.3 - 220	A
Average beam current	12.4 - 12.8	A
Speed of the beam	0.9712 - 0.9998	
Bunch length	360 - 67	ns
Bunching factor	0.3 - 0.058	
Revolution frequency	186 - 191	kHz
RF frequency	1.67 - 1.72	MHz

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bottom [4]. Therefore the goal is set at the position accuracy of ±0.1 mm and the resolution of ±10 μm. The alignment between the quadrupole and BPM pair will be achieved by making use of beam based calibration.

BPM PICK-UP

Electrostatic pickup with diagonal-cut cylinder is adopted because of its linear response to the position [5]. One BPM set consists of one horizontal and one vertical electrode pairs (Fig. 1). The electrodes and chamber are made of stainless steel, SUS316L and the SMA coaxial vacuum feed through is made of SUS316L brazed with alumina ceramics. The electrodes are supported and insulated with small ceramic block positioned in grooves of the inner surface of the chamber. The coupling impedance is very small. The electrode capacitance is ~210 pF.

Calibration of the position response is going on with a copper wire of ϕ 0.4 mm and the position resolution of ±10 μm. The linear position response, deviation of less than 0.1 mm within r < 40 mm was obtained. The lower cut-off frequency was ~17 MHz (Fig. 2), which differentiates the beam signals. The frequency response of the position sensitivity:

$$\kappa = (L-R)/(L+R)/x$$

is plotted in Fig. 3, where L and R are the output voltage from the left and right electrodes, x is the horizontal displacement of the wire. Reduction of position sensitivity κ at f > ~ 5 MHz is considered due to capacitive coupling between the opposite electrodes. The calculation with this assumption agrees with the measured data (Fig. 4) [5]. This will not affect the COD measurement because the detection frequency is the RF frequency, ~1.4 or ~3.4 MHz.

The wire calibration will be planned for all pickups in this year. Overall position offset relative to the quadrupole center will be identified by beam-based calibration.

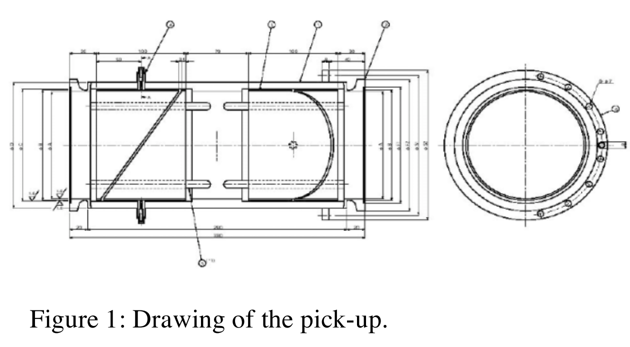

Figure 1: Drawing of the pick-up.

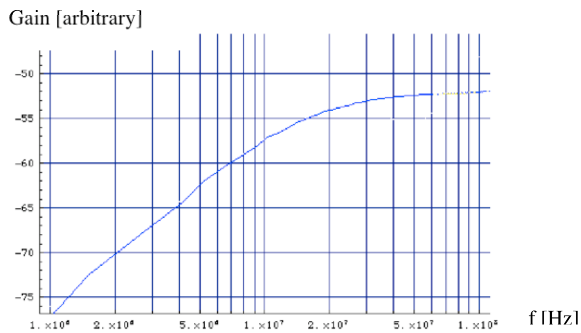

Figure 2: Pick-up response in the frequency domain.

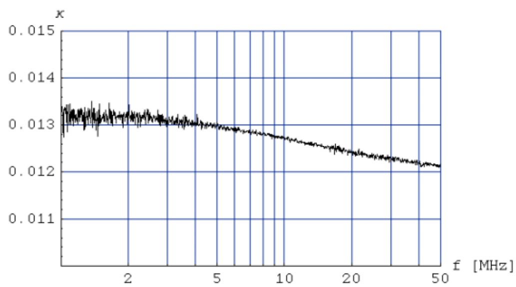

Figure 3: Position response κ measured by the wire method in the frequency domain.

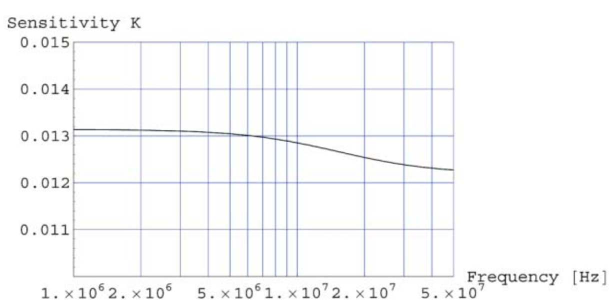

Figure 4: Calculated position response in the frequency domain.

SIGNAL PROCESSING

Four signals from one BPM set are sent to one processing module, which consists of a power supply, analog circuit, 14 bit, 80 MSPS ADC, FPGA and PC in an independent chassis. Five pole Butterworth low pass filter of 10 MHz, provides anti-aliasing. Noise level is < 10 digit without amplification (0.05% of the full scale). Noise with the amplifications are measured as shown in Fig. 5.

Three alternative processing is possible: COD measurement, one pass position measurement and waveform measurement. In the COD measurement, the tailored signals are digitized, 1024 data are fast Fourier transformed using FPGA, then a peak at the RF frequency is obtained. Then Δ/Σ is calculated in an EPICS IO controller (IOC). One pass position is detected with scanning peak and bottom of the digitized signal, then calculating Δ/Σ at every bunch.

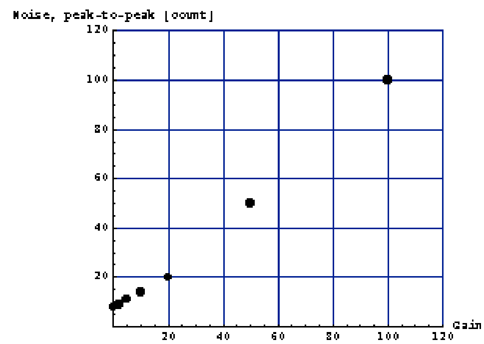

Figure 5: Measured noises of the amplifiers in the processing module. Input was terminated with 50 Ω.

BEAM TEST

To demonstrate the system performance, the pickup and processing circuit was tested with the proton beam at the KEK 12 GeV PS. The beam intensity was 4x10[11] protons per bunch, one hundredth of the design value. The frequency of the RF is 6 MHz, nearly four times larger than J-PARC MR. The COD measured at the injection flat bottom are shown in Figs 1 and 2. Spike-like displacements are due to the leakage fields of the injection pulse septa. Small wiggle is due to ripples of magnets and BPM noise.

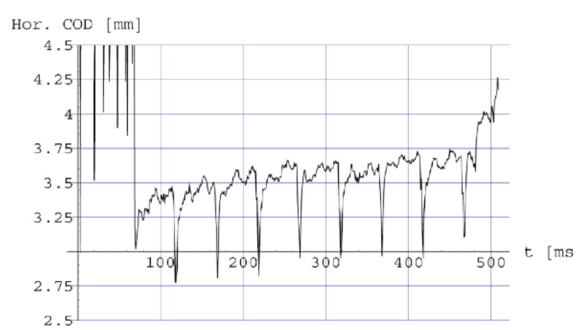

Figure 6: Horizontal COD measurement at the KEK-PS.

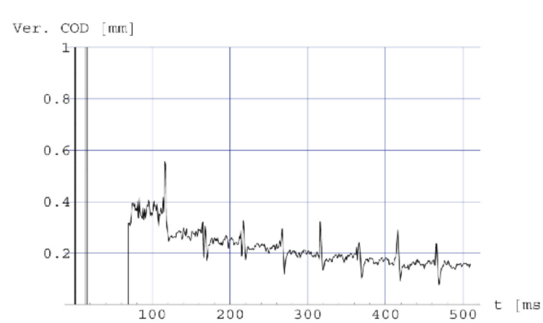

Figure 7: Vertical COD measurement at the KEK-PS.

In the J-PARC MR, 1024 data with 80 M sampling per second is insufficient to achieve enough frequency resolution. Higher frequency resolution, i.e. longer time window at the same data length, 1024, is realized by decimation with a digital low pass filter.

Turn-by-turn position is also measured successfully with a single bunch just after injection as shown in Figs 8 and 9. The betatron tunes ν_x, ν_y, are also successfully obtained by FFT of these data.

Deterioration of performance due to noise is serious problem. Especially the system without front-end electronics has a great risk. One effect observed during the study is noise at the rf frequency. Figure 10 indicates the error occurs only at the RF frequency, 6 MHz in the position sensitivity plot. In this case the cables from the pickup to the processing circuit were 5D2V. Using better cables, 9D-HFBE [7] and common mode choke coils, the noise effect at the rf frequency almost disappeared (Fig. 11). Estimating electromagnetic environment at J-PARC is in progress: EMI from power supplies utilizing IGBT switches, leakage of electromagnetic fields surrounding beams from gaps between vacuum ducts and so on.

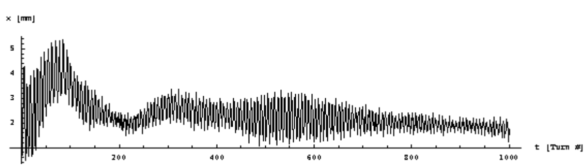

Figure 8: Horizontal turn-by-turn measurement.

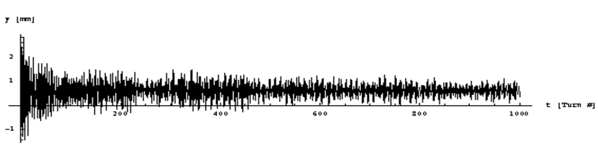

Figure 9: Vertical turn-by-turn measurement.

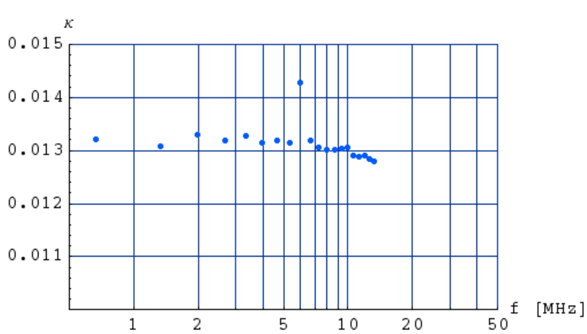

Figure 10: κ measurement at the KEK-PS. The cable was 5D2V, screening effectiveness not sufficient. κ deviates due to the noise at the RF frequency, 6 MHz.

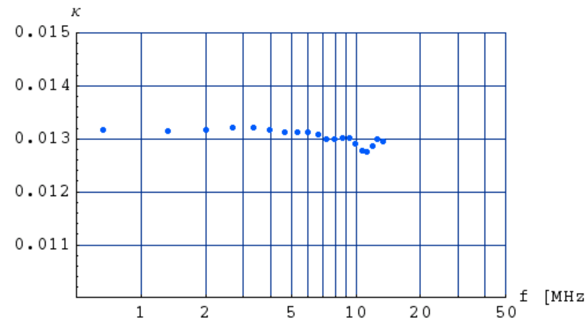

Figure 11: κ measurement at the KEK-PS. With the high screening effectiveness cable, 9D-HFBE.

CONCLUSION

BPM, electrostatic pick-up with diagonal-cut cylinder and processing circuit based on 80 MSPS 14 ADC, was successfully developed. Position accuracy of the pickup within ±0.1 mm is proved with the wire calibration. The processing circuit has enough SNR, 0.05% FS in time domain. Three operational mode, COD measurement, one pass position measurement and waveform measurement, was realized. The preliminary beam test using the KEK-PS shows satisfactory results.

Noise suppression is one of the most important task. Sufficiently high screening-effectiveness cable is now under investigation, compromising between performance and cost. Grounding method is another big issue.

Over all accuracy of BPM setting, ±0.1 mm, will be realized with beam based calibration.

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REFERENCES

[1] Y. Yamazaki, *eds*, Accelerator Technical Design Report for High-Intensity Proton Accelerator Facility Project, J-PARC, KEK-Report 2002-13; JAERI-Tech 2003-044.

[2] J. Odagiri et al, . Proc. of ICALEPCS 2003, 494.
G. Shen et al, submitted to PCaPAC 2005.

[3] S. Machida, memorandum of the beam commissioning group.

[4] S. Machida, submitted to ICFA-HB2004.

[5] T. Toyama et al, Proc. of 14th Symp. Accel. Sci. and Tec., (2003) 470 (Japanese).

[6] N. Hayashi et al, Proc. of 14th Symp. Accel. Sci. and Thec., (2003) 515 (Japanese).

[7] Used for the KEKB BPM. Four coaxial cables (9D-HFBE) are covered with a metal tape and braid.