BEAM DIAGNOSTICS FOR THE J-PARC MAIN RING SYNCHROTRON

T.Toyama*, D.Arakawa, Y.Hashimoto, S.Lee, T. Miura, S.Muto, KEK, Tsukuba, Ibaraki, Japan
N.Hayashi, R.Toyokawa, J.Kishiro, JAERI, Tokai, Ibaraki, Japan

Abstract

Beam diagnostics: beam intensity monitors (DCCT, SCT, FCT, WCM), beam position monitors (ESM), beam loss monitors (proportional chamber, air ion chamber), beam profile monitors (secondary electron emission, gas-sheet) have been designed, tested, and will be installed for the Main Ring synchrotron (MR) of J-PARC (Japan Proton Accelerator Research Complex). This paper covers the basic design principle and specification of each monitor of the MR and the beam transport line from 3 GeV rapid cycling synchrotron to the MR (3-50BT), with a stress on how to cope with high power beam (average circulation current of ~13 A) and low beam loss operation (less than 0.5 W/m except a collimator, injection and extraction region). Some results of preliminary performance test using present beams and a radiation source will be reported.

OVERVIEW

J-PARC 50 GeV Main Ring Synchrotron will feed $3.3\mathrm{x}10^{14}$ protons per pulse (typically in 3.6 s), corresponding to an average current of 12.4 - 12.8 A[1]. Although beam loss in the ring should be controlled in a small amount, < 0.5 W/m, at the arc sections, much more beam loss may occur at the injection, fast extraction, slow extraction and collimator regions. No active devices (semiconductors) for the beam diagnostics will be installed in the tunnel in principle. In the MR two beam current transformers (CT's) for average beam current monitoring, three CT's and two wall current monitors (WCM's) to provide beam phase and loading information for the RF accelerating system, some bunch monitors (CT's and WCM's), 186 beam position monitors (BPM's) almost at every quadrupole magnet, additional pickups for fast measurement up to a transverse quadrupole mode, > 300 beam loss monitors of fast response (proportional mode) almost at every quadrupole magnet, > 40 beam loss monitors of slow response (ionization mode), a gas-sheet beam profile monitor in the ring and secondary electron emission profile monitors for transport lines. Betatron tune will be measured with an rf exciters and BPM's. Electron cloud detector is an optional device in near future.

Initial beam commissioning will be done with 1/100 of the design intensity. Therefore the diagnostics should afford dynamic range of more than 40 dB [2].

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 another way, e.g. ftp [3].

*takeshi.toyama@kek.jp

BEAM INTENSITY MEASUREMENTS

A DCCT and a feedback CT will be used to measure average current in the ring. The dynamic range will be more than 120 mA - 13 A and the frequency response of DC - 10 kHz [4]. Three CT's with the frequency bandwidth > 40 MHz will provide beam phase information for the RF accelerating system. The core will be nanocrystalline soft magnetic material[5], which has large saturation field. Preliminary test with small size core shows core saturation is not critical even at the design intensity. The load resistance should be small not to extract too much power from the beam. A resistor of a few Ω cause resonances at a few 100 MHz because small resistance introduces small damping. Damping the resonance is under study. The WCM's have wider frequency range and two of them will be used to supply beam loading information for the RF accelerating system.

BPM'S

One-pass position and closed orbit will be measured by 186 BPM's. The goal of position accuracy is < 0.1 mm and position resolution is ~10 μm. The precise position measurements and COD correction is crucial to prevent beam losses at the injection flat bottom [6].

Pickup[7]

Electrostatic pickup with diagonal-cut cylinder is adopted because of its linear response to the position. One BPM set consists of one horizontal and one vertical electrode pairs. The electrodes and chamber are made of stainless steel, SUS316L and the SMA coaxial vacuum feed through is made of SUS316L brazed with alumina ceramic. The coupling impedance is very small. The electrode capacitance is ~210 pF and the lower cut-off frequency is ~17 MHz, which differentiates the beam signals. The frequency response to the position is flat up to ~5 MHz. Reduction position response at frequencies higher than ~5 MHz is considered due to capacitive coupling between the opposite electrodes. Position calibration of a prototype pickup with a ϕ0.4 mm copper wire shows the linear position response, deviation of less than 0.1 mm within r < 40 mm. Calibration with a wire will be planned for all pickups in this year. Overall position offset relative to the quadrupole center will be identified by beam-based calibration.

Signal Processing[8]

Four signals from one BPM set are fed to one processing module, which consists of independent chassis, power supply, analog circuit and 14 bit, 80 MHz ADC. Five pole Butterworth low pass filter of 10 MHz, provides anti-aliasing. Noise level is < 10 digit without

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amplification. 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.

Beam test

The pickup and processing circuit was tested at the KEK 12 GeV PS. The beam intensity was 4×10^{11} protons per bunch, one hundredth of the design value. COD measured at the injection flat bottom is shown in Fig. 1. Spike-like displacements in Fig. 1 are due to the leakage fields of the injection pulse septa. Small wiggle is due to ripples of magnets and BPM noise.

Turn-by-turn position is also measured succesfully with a single bunch just after injection.

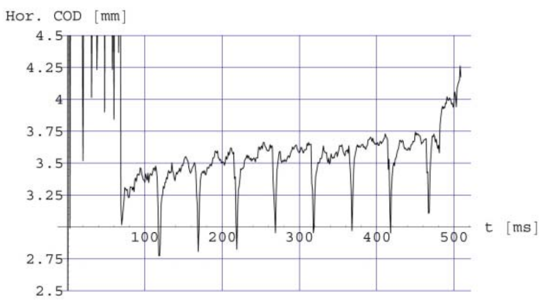

Figure 1: Horizontal COD measurement at the KEK-PS.

BEAM LOSS MONITORS[9]

The beam loss monitors will be used to provide beam loss information for minimization of an uncontrolled beam loss and control of the beam loss at the collimators. Besides the data of the beam loss along the beam lines in time slices and vice versa, this system provides a trigger to the machine protection system (MPS) and the beam abort system in the MR, if integrated beam loss exceeds the preset loss level. This is, therefore, a key instrument to deal with such large beam intensity as 0.75 MW. Proportional counters (P-BLM) more than 300 sets and coaxial cable ionization chambers (AIC-BLM) more than 40 sets will be installed for the MR and 3-50BT.

P-BLM's

P-BPM has triaxial structure: an center platinum wire of ϕ 50 μm, an inner stainless steel cylinder and outer stainless steel cylinder. Negative high voltage > -3 kV is supplied to the inner cylinder. Signals are picked up from the output connector directly connected with the center wire and the outer cylinder is kept at the ground level. After baking in a vacuum, Ar + CO_2 gas is filled at the pressure a little larger than the atmospheric pressure. This process guarantees constant gain under irradiation up to 3.5 mC/mm at least (Fig. 2). The rise time changes depending on the load resistance, ~1 μs at 10 kΩ, which will be utilized to obtain the appropriate signal form. The detectors will be hung at the magnet girders with magnetic shielding.

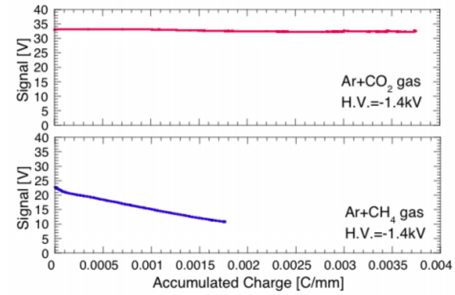

Figure 2: Gain variation due to Co-60 γ ray irradiation.

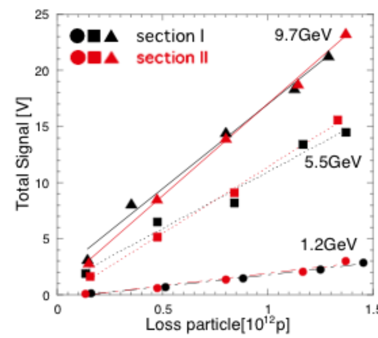

Figure 3: Linearity of AIC-BLM at the KEK-PS.

AIC-BLM's

This kind of detector has been utilized in many laboratories including the KEK-PS and proved its reliability. AIC-BLM has also triaxial structure. The detectors installed in the KEK-PS moe than 20 years ago was recently tested. The results shows that good performance has been kept in the real circumstances: linear response in beam loss and energy (Fig. 3). The drawback is relatively slow response of >1 ms. Fast rise time of ~100 ns may be possible with detectable signal level by 50 Ω load and large beam loss. But this is not the case for the MR. Therefore high impedance input processing circuit will be prepared. AIC-BLM's are used as the reference, relying on its performance and lifetime.

BEAM PROFILE MONITORS

A gas-sheet beam profile monitor is under development as a non-destructive profile monitor in the MR. At the 3-50BT, injection and extraction lines, secondary electron emission monitors (SEEM) with thin foil strips will be utilized.

Gas-Sheet Beam Profile Monitor[10]

This monitor injects a neutral gas jet of thin flat sheet geometry. The circulating synchrotron beams cross the gas-sheet with an angle of 45 degree. A target is a dense pulsed gas sheet beam produced by nozzle beam method. A luminescence light from the target yielded by collision with the synchrotron beam is observed by a fast camera.

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The measurement is not obstructed by a beam induced field because of light detection. For the species as a gas target, nitrogen is put up as a candidate because of fast decay time (< 100 ns) and having intense visible luminescence light (λ=390 nm). The gas density of 5 x 10^{-4} Pa is required for one bunch profile measurement in case of design beam. The gas target generator has been tested for producing intense gas sheet beam. Up to now the gas density is over 1 x 10^{-4} Pa at the 60 cm distance from the nozzle. The monitor specifications is summarized in Table 1. Clearing field to suppress electron clouds can be supplied from the upper port.

Table 1 : Sheet Beam Profile Monitor specifications

Gas density (Target point; 60 cm from the nozzle)	5 x 10^{-4} [Pa] (design value) 1.6 x 10^{-4} [Pa] (achieved)
Gas sheet size	100^{W} x 250^{L} x 1^{T} [mm]
Target uniformity	< +/- 3 %
Gas species	N_2 (candidate)
Measurement Cycles	30 [times/sec]
Measurement Time	< several bunches
Vacuum contamination in the ring	< 1 x10^{-6} [Pa] (within 1m)
Wave length of luminescence light	390 [nm] (N_2)
Fast gated camera	Visicon camera attached image intensifier

SEEM[11]

Survival under the high intensity proton beam and low beam loss at the SEEM are big issue. Several target materials has been irradiated by proton beams and ion beams to confirm radiation hardness. Among aluminum coated polypropylene, aluminum and carbon, thin carbon foil is promising. The efficiency of secondary electron emission was ~ 1-2 %. The estimated beam loss is a few W at the design intensity. Utility should be carefully arranged, e.g. restricting the number of beam pulses.

Figure 4: Beam profile of the proton beam. Number of protons ~2x10^{12} protons/bunch.

OTHER MONITORS

Quadrupole-Mode Monitor[12]

Non-destructive fast response measurement of quadrupole moment of the beam in transverse plane is under development, using pickups with four electrostatic electrodes. At the KEK-PS beam, average quadrupole moment and then average beam emittance was obtained. Turn-by-turn measurement is the next subject.

Flying Wire Beam Profile Monitor[13]

At the initial commissioning the flying wire profile monitor which will be similar to the one at the KEK-PS will be used with small intensity. This will complement the gas-sheet beam profile monitor.

Electron Cloud Detector[14]

Electron cloud is a big issue not only for beam instabilities but also as a noise source for beam diagnostics. Several electron cloud detectors as the one in the KEK-PS will be installed.

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