BEAM DIAGNOSTIC SYSTEM OF THE MAIN RING SYNCHROTRON OF J-PARC

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Abstract

The J-PARC MR beam monitor system have been installed and tested at day-one beam commissioning started this May. In this paper, the requirements for the monitor system to achieve high power beam acceleration up to 50 GeV, 0.73MW, and the present performances are presented.

INTRODUCTION

Japan Proton Accelerator Research Complex (J-PARC) Main Ring synchrotron (MR) will generate 50 GeV, 0.73 MW beams followed by 3 GeV beam bunch injection from Rapid Cycling Synchrotron (RCS) [1]. The beams are used to generate secondary particles like Pion, Kaon, Anti-proton, and Neutrino to investigate nuclear and particle physics.

The day-one beam commissioning has been started from this May. Up to now, the commissioning was made under DC operation. The Table 1 shows the comparison between designed beam parameters and day-one beam parameters. Number of particles in a bunch was 4×10^{11} ppb (particle per bunch), that is 1/100 of the designed one, and the measured peak current was 3 A. Only one bunch beam was injected, thus the circulating beam current is about 3 orders of magnitude smaller than the designed one. The beam was extracted to the beam dump after 1000 turns.

An AC mode operation will start from this December, however the maximum energy is 30 GeV at phase-one.

Table 1: Designed Beam and Day-One Beam Parameters

	Design	Day-one	unit
Prticle per pulse	3.3×10^{14}	$4\text{-}5\times10^{11}$	ppp
Number of bunch	8(h=9)	1(h=9)	
Peak current	41.3-220	3	A
Circulating current	12.4-12.8	0.12-0.14	A
Velocity	0.9712-0.9998	0.9712	1/C
Bunch half width	180-33.7	40-60	ns
Revolution frequency (1/f)	186-191(5.38-5.24)	186(5.38)	Hz(μs)
RF frequency (1/f)	1.67-1.72(599-581)	1.67(599)	Hz(ns)

OVERVIEW OF THE MONITOR SYSTEM

We have been developing various beam monitors aiming for the precise control of the MW class high power beam. Almost all the monitors were installed and used to establish the beam operation parameters at the day-one beam commissioning. Some monitors are now under development.

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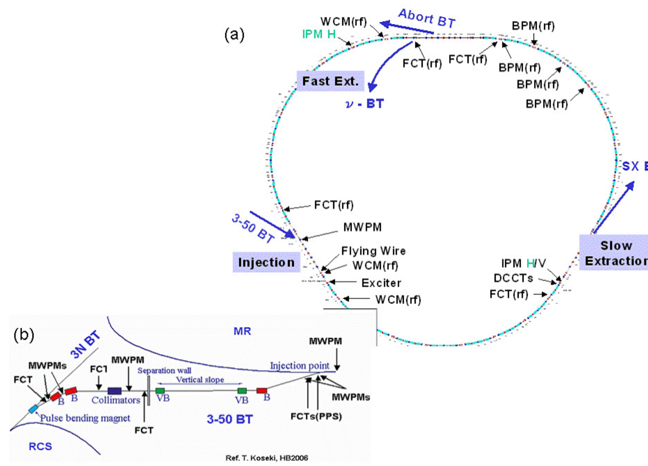

Figure 1: Monitor arrangement for the MR (a) and for the 3-50 BT (b).

Figure 1 shows arrangements of the beam monitors of the 3 GeV RCS to 50 GeV MR beam transport (3-50 BT) and of the MR, respectively. Table 2 shows the number of the monitors, where the blue ones show the monitors which will be installed from now on.

Table 2: List of the monitors for the MR and the 3-50 BT. The blue characters shows monitors which will be installed.

	MR	3-50 BT
Monitor	Number	Number
ring BPM	186	
Single-pass BPM	2	14
Dump/abort BPM	2+2	
WCM(>100MHz)	3	
FCT(∼20MHz)	6+1(ν-BT)	5
DCCT(DC∼30kHz	2	
MWPM	1(inj.), 2(SX, Abort BT)	5+4
Flying Wire (H/V)	1/1	
IPM(H/V	2/1	
BLM		
Proportional Chamber	238	50
Air Ionization Chamber	18	3

Beam position monitors (BPMs) are installed near almost all Q-magnets; these are installed inside the steering magnets to save space. Proportional type Beam Loss Monitors (P-BLMs) are installed at each Q-magnet and some are also installed around important areas, injection section, along dump line, and near beam collimaters. Some coaxial cable base air ionization chamber type BLMs (AIC-BLMs) are also installed. Three types of Current Monitors

(CMs) are installed, DC Current Transformers (DCCTs), Fast Current Transformers (FCTs), and Wall Current Monitors (WCMs). One set of horizontal and vertical exiciter is installed to excite betatron oscillation to measure tune. Multi Wire Profile Monitors (MWPMs) are installed and mainly used at 3-50 BT, and a Horizontal type Frying Wire Monitors (H-FWM) and a Vertical type residual gas Ionization Profile Monitor (V-IPM) are installed in the ring.

For a high power accelerator, it is essential to reduce beam loss to protect accelerator components from vital damage from radiations induced by beam loss. The beam power of the MR will be about 500 times larger than that of KEK 12 GeV Proton Synchrotron (KEK-PS) and over 3 times larger than that of ISIS accelerator, although the beam loss criteria, which was determined by taking into account the maintenance scenario, is nevertheless 0.5 W/m that is same level as KEK-PS; that is, the MR needs quite severe operation with quite low beam loss condition.

The criteria means that the beam loss ratio should be less than 1.8 % when 3 GeV and less than 0.1 % when 50 GeV, respectively. To meet the severe beam control, the BLM and DCCT required to have wide dynamic range over 10^4. The required position resolution of the BPM system is 0.1 mm despite the large aperture ring. The typical beam duct bore is 130 mm. For the profile monitors, the beam halo monitoring is required to investigate the halo formation mechanism because the halo formation may limit the maximum beam intensity.

BPM

We have installed 2 types of electrostatic type BPMs.

For the MR, we adopted a diagonal cut model BPM (ring BPM) to obtain good linearity over full aperture. Bores of the ring BPM are 130, 134, 165, 200, and 320 mm, here the standard is 130 mm. The other is quad parallel type BPM (single pass BPM) mainly used at the 3-50 BT. Bores of the single pass BPM are 200 and 230 mm.

The sensitivity was calibrated by wire method before installation. The resolution of the sensitivity, position offset, and rotation were $\pm$0.00004, $\pm$0.12 mm, and $\pm$3.6 μrad in rms, respectively. After installation, we measured alignment error to the center line of the nearby Q-magnet and obtained $\triangle$x=0.41$\pm$0.96 mm, $\triangle$y=-0.35$\pm$0.50 mm, and rotation=0.96$\pm$3.3 mrad.

For the single pass BPM, the waveform data are obtained by using 8 bit, 100 MHz, 2 GS/s oscilloscopes. For the ring BPM, to estimate the COD, the following processes are adopted. 1) At an arbitrary time, 4096 sampling points of a waveform signal are obtained by using 14 bit, 80 MS/s ADC, 2) A series of 4 sampling points are averaged and thus 1024 data points are obtained, 3) Using the averaged data, the spectrums are obtained by FFT method, 4) 3.4 MHz components are used to calculate a beam position to exclude noise components below 2 MHz.

CURRENT MONITORS

To monitor beam intensity, we have installed 2 DCCTs whose toroidal cores are made of Finemet [2]. The frequency band is DC to 2 kHz. The amp gain is selectable between 0.2, 2, 20A/10V. The resolution of the measured beam current was, in typically, 100 μA when the amp gain was 0.2A/10V. The beam current is devided by the RF frequency to obtain beam intensity.

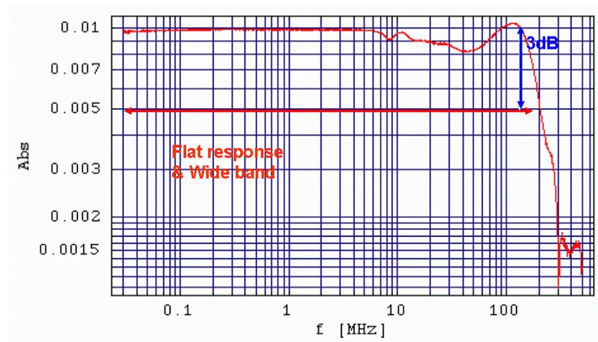

Figure 2: Frequency responce of the FCT.

To measure a bunch shape, we have installed FCTs and WCMs. The toroidal cores of the FCTs are made of Finemet [2]. The typical frequency response of a FCT is shown in Fig. 2. As can be seen in the figure, the wide frequency band of 16 Hz to 180 MHz is achieved. The FCTs are also used for RF phase feedback system. The WCM outputs beam induced voltage on resistors set crossing a ceramic insulator tube. To reduce wall current through a metal housing of the WCM, an inductance made of Finemet [2] is set in the metal housing. The WCMs are also used for RF feed-forward system to compensate beam loading.

BLM

To obtain wide dynamic range, the P-BLM was adopted. Details of the BLM system are reported in ref. [3]. Fig. 3 shows schematic drawing of the P-BLM. The gas component is 1 atm Ar mixed with 1 % CO_2.

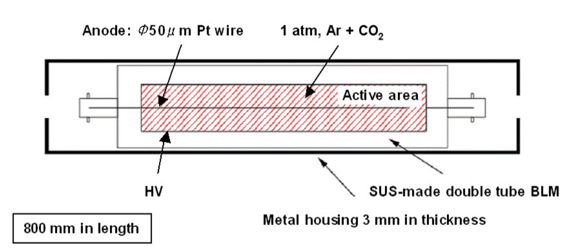

Figure 3: Schematic drawing of the P-BLM.

To check dependence of the bias voltage on the gain, the secondary cosmic rays, mainly muons, were used. At an arbitrary bias voltage, a pulse signal from P-BLM induced by a single muon was amplified by the charge sensitive preamp. Then the output signal was processed with pulse shaping amp and each pulse height was analyzed by the multi channel analyzer to obtain a gain spectrum. The maximum gain was 6×10^4 when the bias voltage was 2kV.

A charge signal form the P-BLM is directly input to the main amplifier which has selectable input impedance of 50 Ω and 10 kΩ and selectable gain of 10, 100, and 1000. The amplifier outputs waveform signal and also outputs integrated signal. The integrated signal is used to serve alarm signal to machine protection system (MPS). Fig. 4 shows beam loss monitoring display, where the bar graph shows the integrated signal.

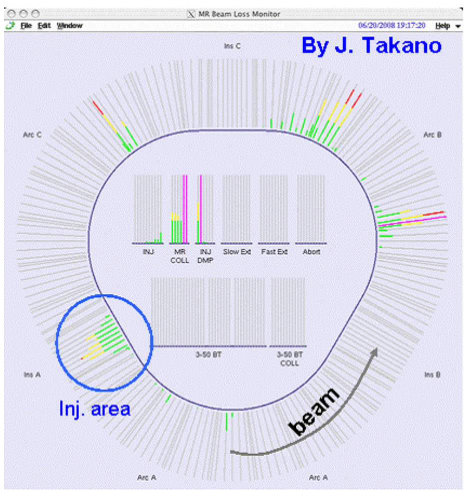

Figure 4: Beam loss distribution montoring display.

TUNE MONITOR

To excite betatron oscillation, we installed horizontal and vertical exciter consists of 50 Ω strip line kicker and power amp. The maximum input power is 2 kW. The frequency components of the signal from the BPM are analyzed by real time spectrum analyzer to obtain tune. The resolution of the measured tune was 0.007.

PROFILE MONITORS

Three types of profile monitors, MWPMs, H-FWM, and V-IPM have been installed.

The MWPMs are mainly used at the 3-50 BT. Tungsten wires of 30 μm are used. A number of the wire is 32 or 64, and pitch size is 2.5 to 4.5 mm. A signal from each wire is amplified and multiplexed. The wires will be replaced by carbon ribbons to increase the signal level.

The H-FWM is used to measure horizontal profile of the MR beam. A 7 μm carbon fiber moves to across the beam with 10 m/s. The radiations induced by the beam interaction with carbon fiber are measured by scintillator set downstream. A profile can be measured at every 0.1 s.

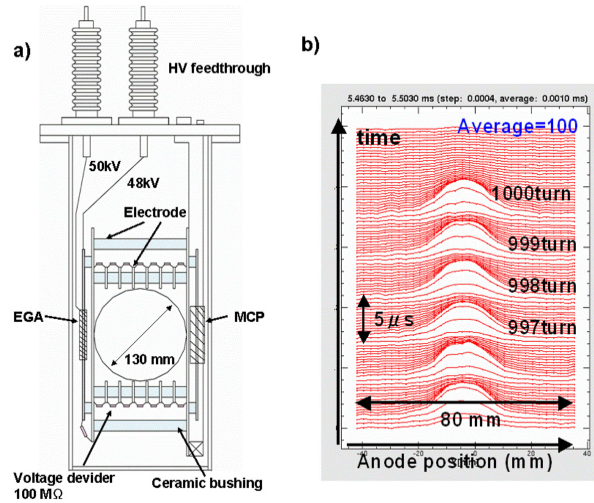

Figure 5: Cross section veiw of the V-IPM (a) and measured profile (b).

The V-IPM is a nondestructive beam profile monitor. Fig 5-(a) shows schematic drawing. The V-IPM collects the ions generated by the ionization process between circulating beam and residual gas. The maximum HV is 50 kV. A two-stage Micro Channel Plate (MCP) with 32 ch strip anodes is used as the signal multiplication and signal readout devise. The electron source EGA [4], are used to check gain of the MCP. The waveform from each anode is digitized by using oscilloscopes whose band width, sampling speed, and data length are 200 MHz, 100 kS/s, and 1 M words, respectively. The obtained turn by turn beam profiles are shown in fig 5-(b). The profiles were obtained by averaging over 100 pulses to reduce high frequency noise, statistical error due to small number of detected ions, and signal level fluctuation due to broad gain distribution of the MCP.

CONCLUSIONS

We have been developing various beam monitors aiming for the high power beam acceleration up the designed power. The requirements for the monitor system were presented. The monitors have been used during day-one beam commissioning and demonstrated good performance. However, some monitors are needed to be improved to meet the requirements. The improvement of the dynamic range is likely to be an essential and a challenging issue.

REFERENCES

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[4] ELECTROGEN^{TM}, PHOTONIS, Ltd.