BEAM DIAGNOSTICS AT THE FIRST BEAM COMMISSIONING OF THE J-PARC MR

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Abstract

J-PARC MR was successfully commissioned with single bunch accumulation and the beam intensity of typically 4x10^{11} protons per bunch, 1% of the design value. Beam diagnostic devices: current monitor's (DCCT, FCT, WCM), BPM's, BLM's, profile monitors (SEEM, luminescence screens, FWPM, IPM) and tune meter have come into operation. Using outputs from these devices, beam related physical quantities were obtained with enough precision.

INTRODUCTION

The MR is a 50 GeV proton synchrotron at J-PARC, Japan proton accelerator research complex, which will feed 3.3x10^{14} protons per pulse typically in 3.6 s, corresponding to 750 kW[1]. At the first commissioning the beam was stored at the 3 GeV flat-bottom and extracted to the injection beam dump in May, June 2008, and in Dec. 2008 accelerated up to 30 GeV and extracted to the abort beam dump. In Jan, Feb and Apr. 2009, the 30 GeV beam was extracted to the hadron beam dump and then neutrino target[2]. These commissioning was done with the beam intensity of 1-4x10^{11} protons/bunch, less than 1 % of the design value (Table 1). Beam monitors are summarized in Table 2[3].

Table 2: Beam Monitors

monitor	#
3-50 BT	
FCT (fast CT)	5
SEEM (secondary electron emission monitor)	5
BPM (beam position monitor)	14
BLM (beam loss monitor)	50
MR	
DCCT (direct current CT)	2
FCT (fast CT)	7
WCM (wall current monitor)	2
BPM (beam position monitor)	186+4
BPM (stripline)	2
BLM (beam loss monitor)	238
SEEM (secondary electron emission monitor)	1
Luminescence Screen	5
FWPM (flying wire profile monitor) (H/V)	1/(1)
IPM (ionization profile monitor) (H/V)	1+(1)/1
Tune meter (H/V)	1/1

Table 1: Beam Parameters at "Day-one" and Design

	day-one	design	
Proton number	$< 4\times10^{11}$	4×10^{13}	p/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
β	0.9712 - 0.9998		
Bunch	40 - 70		ns
f_{rev}	186 - 191		kHz
Revolution period	5.38 - 5.24		μs
RF frequency	1.67 - 1.72		MHz

BEAM INTENSITY MONITORS

Two DCCT's are used to measure circulating current in the MR. The parallel feedback loop minimizes the defect due to variation of core magnetic characteristics[4]. The nanocrystalline soft magnetic material, Finemet[5], is used as a core. The full scale is 0.2, 2 and 20 A and the resolution is ~100μA. The frequency response is DC-20 kHz. The frontend electronics is located in the sub-tunnel, ~30 m apart from the detector to avoid radiation damage. At the LCR (local control room), an analog processing circuit outputs the current signal, and normalizes with the rf frequency to obtain the beam intensity. This signal is divided to a digitizer (16bit, 40kHz, 100kSPS), and a beam spill feedback system for slow beam extraction.

FCT's have the frequency bandwidth of 16 Hz to 180 MHz. The core is the Finemet, which has large saturation field. The secondary winding (25 turns for 3-50BT, 50 turns for MR and the ν-BT) is terminated with 25 Ω, two 50 Ω resisters in parallel. The anti-resonances due to transmission-line-like characteristics of the core-coil-chassis system are damped with 100 50Ω-resistors and the resonance due to the cavity structure of the chassis is damped with 36 180Ω-resistors. The signal is transferred to the LCR, through 20D coaxial cables from 5 FCT's in the 3-50BT and 12D coaxial cable from the neutrino BT, and double-shielded 20D coaxial cables from 7 FCT's in the MR. The signals from the 3-50BT and ν-BT are integrated with a time constant of 160μs, scaled to 10^{14} protons/10V, digitized with ADC's (10V, 12 bit, 10 kSPS), and logged by PLC's[6]. Two of the 3-50BT FCT's are used for the PPS (Personel Protection System). Three of the MR FCT's provide beam phase information for the RF accelerating system and one of them timing information for the FX/abort kicker system.

Three WCM's are prepared, two for RF beam loading cancellation system and one for observation. The ceramic break of the SUS316L beam duct are bridged with 92 mΩ-resistors. The load is 25 Ω, two 50 Ω resisters in parallel. The core to prevent the wall current flowing the shielding chassis is Finemet. The sag is 0.36 ms - 1.05 ms, varying with core permeabilities. At higher frequencies the gain is gradually increasing from a few 10 MHz to more than 1 GHz. The increment is ~36 dB. This is partially canceled by the cable attenuation. At the design intensity the heat load of the gap resistors, 40-50 W, will be cooled with an air blow system.

BEAM POSITION MONITORS

One-pass positions are measured with 14 BPM's in the 3-50BT, 2 BPM's in the injection beam dump line and 2 BPM's in the abort beam dump line. MR closed orbit as well as one-pass position are measured with 186 BPM's[7]. For the MR, we adopted an electrostatic pickup with a diagonal-cut cylinder or racetrack duct to obtain good linearity over full aperture. Bores of the diagonal-cut BPM's are ϕ130, ϕ134, ϕ165, ϕ200, ϕ257 and 140x302 mm, here the standard is ϕ130 mm. The other is a quad parallel type BPM used at the 3-50 BT and the injection beam dump line. Their bores are ϕ200, ϕ230 mm and ϕ320.

To obtain enough signal power at the initial weak beam commissioning, the original desgin, that is adding external capacitors at the diagonal-cut BPM's, was changed. Present design is without capacitors at the head and adding controllable attenuators in front of the processing circuit to reduce the signal power at higher intensity beam operation. To the quad parallel type BPM heads, the transformers were attached to extend the lower cut-off frequency. The DC connection capability is remained for the ring BPM's, foreseeing the electron clouds.

The electrical error of the BPM head was corrected using the stretched wire method. Alignment error was corrected using the survey data with the laser tracker. The statistics of the results are as follows,

for BPM heads:

sensitivity	Δg_{LR}, Δg_{UD}	±0.3 % (rms),
offset	Δx, Δy	±0.12 mm (rms),
rotation	$\Delta\theta_x$, $\Delta\theta_y$	±3.6 mrad (rms),

for alignment:

offset	Δx	0.41±0.96 mm (rms),
	Δy	-0.35±0.50 mm (rms),
rotation	$\Delta\theta_x$, $\Delta\theta_y$	0.96±3.3 mrad (rms).

Each error was corrected in the EPICS data processing routine. For higher accuracy, beam based alignment is foreseen.

The position resolution at single bunch operation of ~3.5×10^{11} ppp is estimated less than ±0.5 mm by three BPM correlation analysis[4]. Higher resolution is obtained by many shot averaging at the same machine condition.

BEAM LOSS MONITORS

Proportional counters (P-BLM) are installed for the 3-50BT and MR[8]. For the coaxial cable ionization chambers (AIC-BLM), only the heads and signal transmission lines are prepared at day-one.

The P-BLM comprised the Pt wire of ϕ50 μm, stainless steel tube of ϕ23 mm, and Ar (99%) and CO_2 (1%) gas mixture. The signal is transferred through the 8DFB coaxial cable to the LCR, divided into two parts, in the analog processing circuit, one is a fast analog signal and the other is integrated signal. Either signal is compared to the reference voltage and the alarm voltage level is sent to the MPS system if the condition satisfied. The alarm signal was masked during the initial commissioning because the beam intensity was weak enough.

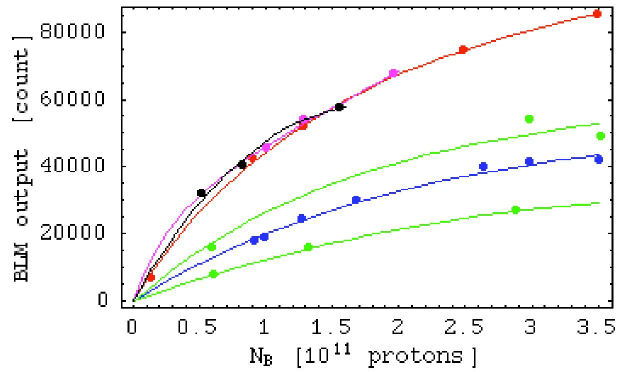

Figure 1: BLM output as a function of the number of lost protons. Green: Arc, blue: slow extraction, red: MR collimator, magenta: fast extraction, black: injection beam dump. At the BLM gain of ~2300 (HV = -1.6 kV).

The integrated signal is sampled with an ADC (±10V, <2kSPS, 12bit) and processed on the EPICS IOC[9]. All integrated signals are stored on the disk using EPICS archiver and can be reviewed afterward.

The P-BLM gain was calibrated using the cosmic ray. The BLM output is proportional to the beam loss. The proportionality constant depends on details of geometry. The computer simulation using computer codes like MARS and PHITS is going on. Besides, the constant was empirically measured at several important areas (Figure 1) and used for loss estimation.

BEAM PROFILE MONITORS

At the 3-50BT, injection and extraction lines, SEEM with wire or thin foil strips is in operation. In the MR a flying wire profile monitor for the horizontal plane and two IPM's for the horizontal and vertical planes are utilized. Five luminescence screens and one SEEM are used at the slow extraction beam line.

SEEM

In addition to an ordinary tungsten-wire target, a high-radiation-resistant low-beam-loss target was developed utilizing thin carbon-graphite strips[10]. The carbon-graphite sheet of thickness 1.6 μm is attached on the alumina ceramic frame and cut by the laser with the position precision of 10μm. The electron yield uniformity is determined to be less than 1% using the test beam in HIMAC. Two carbon-graphite SEEM's are installed at the 3-50BT and SX BT.

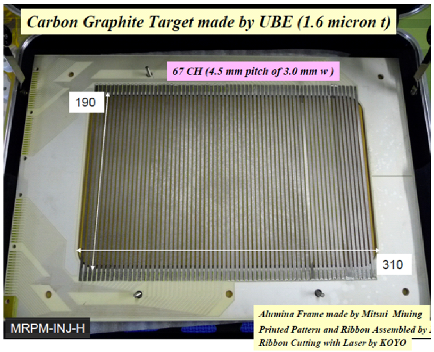

Figure 2: SEEM using carbon-graphite ribbons.

IPM

The present IPM's collect ions generated by the ionization process between a circulating beam and residual gas [11]. The maximum collecting HV is 50 kV. A two-stage Micro Channel Plate (MCP) with 32 ch strip anodes is used as the signal multiplication and readout devise. The electron source EGA is used to check gain of the MCP. The waveform from each anode is digitized 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 Figure 3, where the signals are averaged 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.

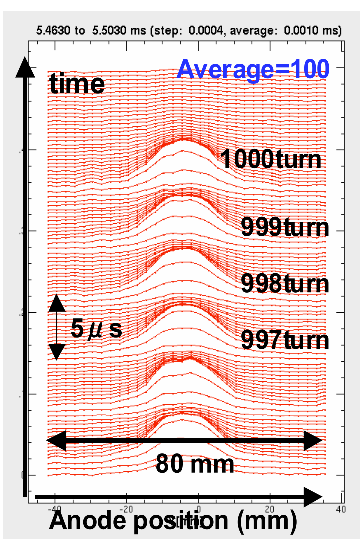

Figure 3: Measured vertical beam profile.

Flying Wire Beam Profile Monitor

The H-FWPM comprises a ϕ7 μm carbon fiber, moving across the beam within 10 m/s, and a scintillator set downstream[12]. One set for horizontal plane is installed at present. The radiations induced by the beam interaction with carbon fiber are detected. The emittance value measured using the H-FWPM was consistent with the one using the SEEM's at 3-50BT and also using H-IPM.

TUNE METER

Horizontal and vertical exciter is installed to excite betatron oscillations. Each consists of a 50Ω strip-line kicker and two power amps. The maximum input power is 2 kW. The signals from BPM's are analyzed by a real time spectrum analyzer to obtain tune. The resolution of the measured tune was 0.007 with the present setup.

CONCLUSION

The beam monitor design aiming for the high intensity proton beam as 750kW is reviewed. The initial weak beam commissioning of the J-PARC MR was performed satisfactory with the aid of some monitors as luminescence screens and flying wire profile monitors, not useful for high intensities. To measure the design intensity beam, BPM's will be attached attenuators, low sensitive BLM's, ionization chambers, will be installed at the high radiation areas like collimators and the slow extraction section, IPM's should realize electron collection. Beam based alignment of the BPM's, a quadrupole mode measurement and a transverse feedback damper are also foreseen.

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