BEAM INSTRUMENTATIONS FOR THE J-PARC RCS COMMISSIONING

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Abstract

A 3-GeV Rapid-Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) has been commissioned recently. During its beam commissioning, various beam diagnostic instrumentation has been used. The multi-wire profile monitor (MWPM) is used to establish injection and H0 dump line, which transports un-stripped H- or H0 beam to the dump. The electron catcher confirms that the beam hits a charge exchange carbon foil and the specified current monitor limits the beam current to the H0 dump. Single pass BPM which detects linac frequency (324MHz) and ionization profile monitor (IPM) helps to check the one pass orbit without circulation of the beam. The beam position monitor (BPM) can measure both COD and turn-by-turn position. Tune monitor system consists of exciter and its own BPM. The exciter shakes the beam and coherent oscillation is measured at BPM. Dedicated BPMs, Fast CT (FCT) and Wall Current Monitor (WCM) are used for RF feedback or feedfoward control. It will describe the performance of each instruments and how they are contributed to the successful beam commissioning.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) is now constructing at JAEA Tokai campus. The RCS (Rapid-Cycling Synchrotron) is the J-PARC second accelerator and it provides 1 MW beam to the MLF (Material and Life science experimental Facility) and MR (Main Ring; 50GeV proton synchrotron) [1]. The RCS has been beam commissioned since September 2007 [2] and it will start to provide the beam to the experimental facilities in the end of 2008. The beam diagnostic system has an important roll for the beam commissioning. They are developed in the recent years [3,4]. Table 1 lists number of instruments in the ring. This paper describes instruments that were used for the RCS beam commissioning.

BEAM COMMISSIONING MODE

There are four commissioning modes, depending on which the beam dump is used and whether beam is circulated or accelerated. These are, (1) H0 dump mode, (2) 1/3 mode, (3) DC mode, and (4) AC mode.

Fig.1 shows overview of the RCS. If the carbon foil is not inserted, the injected beams go to the H0 dump (Injection Dump). This mode is used to establish the injection and H0 dump line. If the DC kicker is on, the injected beams go to the 3N dump without circulating the ring. Because of its simplicity, a lot of time is spent with DC mode. Finally, AC mode is established.

Table 1: Summary of the beam diagnostic system.

Monitor	**RCS**
BPM (COD)	54
for RF	3
single pass	2+2
for ν-meter	1
DCCT/SCT	1/1
MCT	1
FCT/WCM	1/2
At H0 dump line	1/0
for RF	2/1
Exciter	2
IPM	2
MWPM	7
BLM	90/24/ 20

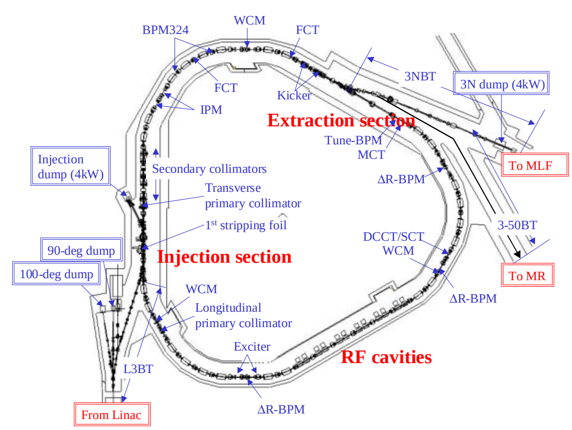

Figure 1: Layout of the J-PARC RCS.

According to the time structure, two parameters are used. They are macro pulse length and chopping width (intermediate pulse length). Together with the linac peak beam current, and numbers of bunch selection, the beam intensity is determined.

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MULTI WIRE PROFILE MONITOR

There are seven Multi-wire profile monitors (MWPM) and six of them are used during H0 dump mode and 1/3 mode. Since MWPM is destructive monitor, they are used only for one pass mode, not circulating mode to avoid multiple beam hitting and large beam loss. The sensitivity is very different for H- ion or H+ beam. Four MWPM are in front of foil and they see always H- beam. Other three MWPM are behind of the foil and their preamp gain has to be changed depending on the sign of ion charge. Injection bump magnet is a source of big noise. It is excited during several hundreds micro seconds. To avoid this, the charge signal is integrated with tens of micro second after bump magnet is turned off. The wire pitch is 3 or 10 mm for u-, v-plane which are 17.7 degree tilted. The wire frame is scanned with 0.1mm step for 10mm. It makes improve spatial resolution.

Typical beam condition is that the Linac beam current is 5mA, the intermediate pulse length is 560ns, and the macro pulse length is 50μs. It corresponds to 4.2×10^{11} protons per pulse. If the other parameter, like peak current, has been changed, chopping length is modified so that to keep an intensity with the same level. Their detail parameters, design and performance are described separately [5]. The data taking system and its online software is also presented [6].

The electron catcher is placed close to the foil. It collects knock out electrons. It is useful to check if the H- beam hits the foil or not.

BEAM POSITION MONITOR

There are 54 beam position monitor (BPM) for mainly COD measurement. It is electro static type and four electrodes are rotated 45 degree due to limited space. Its detail is described in ref. [7]. In addition to that, there are four special BPM for observing the injected beam. Two of them are located at the L3BT line before the ring and others are in the first arc-section of the ring. They are tuned to detect 324MHz frequency, which is the Linac RF frequency. This higher frequency relative to RCS RF, the signal is robust against noise. Although this frequency part dismissed after a few turn in the ring. It is useful to check the lastly injected beam information.

Three BPM are used for RF radial feedback. Those are located at large dispersion section. Those are similar to normal BPM, but they have only two electrodes, to be sensitive to horizontal direction, while normal one has four electrodes. In order to be fast enough for feedback, they are connected to analogue circuit, which is an ideal diode detection circuit. Its sensitivity is set to 5mm/V. Two outputs are passed to RF system.

The last one is initially dedicated for tune measurement. It has four electrodes for horizontal and vertical measurement. It is not rotated like a normal one. It is also used for monitoring injection error [8].

CURRENT AND BUNCH MONITOR

There are two current monitors, DCCT and SCT (Slow Current Transformer). MCT (Medium CT) is used for observing a progress of multi-turn injection. There are three FCT (Fast CT) and three WCM (Wall Current Monitor). Two of FCT and one WCM are assigned for RF phase feedback or feed-forward for the compensation of the beam loading. During the commissioning, they are not fully used for beam control. Rather, they are used to study synchrotron motion. Their vacuum chambers have a ceramic gap, and the inner diameter is 297 or 257. The length along the s-axis is 200mm for FCT and WCM.

The core of DCCT head and electronics were purchased from Bergoz [10]. The core is inserted into the additional magnetic shield case. It has three current range, 0.15A, 1.5A and 15 Ampere full scale. Its higher frequency cut-off (-3dB) is 10~20kHz within all ranges. It has a very good linearity. The SCT has also three ranges as same as DCCT and its higher cut-off is in the range of 14~16kHz. The output signal of DCCT and SCT are connected to normalizers. It divides the beam current by RF frequency, and it gives an output signal which is proportional to the number of protons. Typical signal of DCCT and SCT is shown in Fig.2. The DCCT and SCT are used to measure beam transmission efficiency by comparing with initial and final numbers of protons. To make sure either fast current drop exist or not, WCM information is also used.

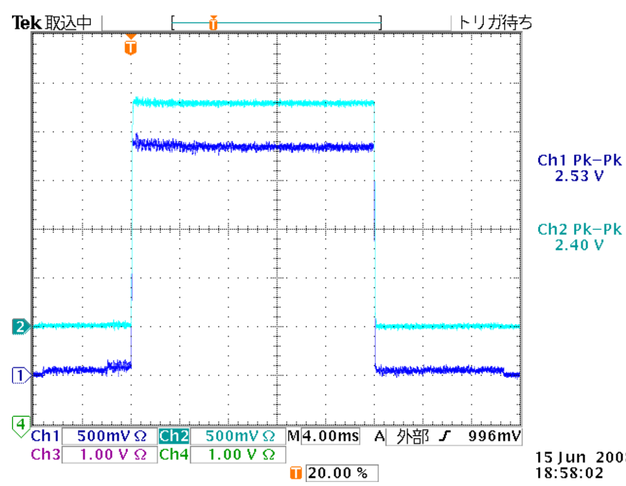

Figure 2: Signal of DCCT (lower; dark blue) and SCT (upper; sky blue) at intensity of 5×10^{11} ppp.

Except DCCT, all toroidal cores are made of FINMET (FT3M) [9] and its size is width of 50mm (a pair of 25mm width), 390mm inner and 470mm of outer diameter. Magnetic susceptibility may differ more than 20%. So, we use the same dimension of the core, and choose good core for severe criterion of the WCM. To adapt different time constant, number of turn is specified. For SCT, a pick up coil is 1000 turns and second feedback coil has 66 turns. Number of turns is 1000 for MCT and 20 turns for FCT.

Shunt impedances are 50, 1 and 0.1 ohm for MCT, FCT and WCM, respectively. For back termination, 50Ω resistor is inserted. As results, sensitivities are 0.025 or 0.050V/A for MCT, FCT or WCM. Since there are no pre-amplifier in the tunnel, it is rather low for less than one percents of the designed beam current. But it is necessary to extend lower frequency cut-off. In case of WCM, small impedance is also required to suppress heat load. All monitors, except WCM, have a calibration coil on the core. They are useful to calibrate even after installation.

MCT, FCT and WCM are measured their frequency response with a taper calibration kit which maintains 50 Ω transmission line. They show good response below the specified frequency. However, all of them have resonance at higher frequency. For example, WCM has a peak around 400MHz.

One FCT is installed at in front of H0 dump in order to measure the beam current to the H0 dump. It is different from the normal FCT, the output is connected to the pre-amplifier in the substitute machine tunnel.

BEAM LOSS MONITOR

There are three kinds of BLM. S-BLM is consists of Scintillator with PMT (photo-multiplier tube). It is fastest response. P-BLM is proportional chamber with Ar-CO_2 mixture gas. AIC-BLM is an air ionization chamber modified from a coaxial cable. It is expected to be stable for longer period, though they are not in operation yet. The output of P-BLM is connected to the machine protection system (MPS), which stops beam operation if beam loss becomes large.

Beam loss at arc area (higher dispersion section) is very sensitive. For example, when the beam chopping was not enough at Linac, the BLM at arc-section shows a certain beam loss immediately. It also indicates that the RF voltage seems the power is not enough. Precise quantitative discussion is given in ref. [11].

TUNE MONITOR

Two exciters at third arc-section give a dipole kick to induce coherent betatron oscillation for either vertical or horizontal. The signal from the dedicated BPM is feed to a Real-time Spectrum analyzer with switch either horizontal or vertical difference. The data is transferred to the PC to make flexible offline analysis. In the case of DC mode, a sampling time can be extended longer than the spec of the analyzer, one can get better frequency resolution. Sometimes injection error is good source to measure tune without using exciter. Although, in case of AC mode, to excite sideband for entire acceleration period is bit trouble.

IONIZATION PROFILE MONITOR

There are two Ionization Profile Monitors (IPM) in the ring. One is for vertical profile and the other is for horizontal at higher dispersion section. It is capable to operate both electron collection mode and ion collection mode due to its dual polarity of its magnet and collection electrode. In principle, an electron collection mode is faster time response, however, it is weaker against noise. Up to now, we use them with ion collection mode, but it is fast enough to see turn-by-turn bunch behaviour with single bunch operation with hundred shots averaging [12].

They are used to check matching between the injection and the closed orbit. They are also useful to confirm the painting injection by looking at the beam profile width.

CONTROL SYSTEM

There are various devices to be controlled. The HV power supply of BLM or the motor control for MWPM are governed by the PLC. The normal BPM signal processing unit is based on VME and its CPU has a shared memory system to collect fast and large data transfer [13]. Oscilloscopes or other digitizers are used to collect waveform data. Most of devices are to be controlled through EPICS using its defined records.

CONCLUSIONS

Various beam diagnostic systems are presented which have been used during the J-PARC RCS beam commissioning. They demonstrated good performance. Few instruments are still needed to be tuned or improved. An operation with the full designed beam current is still scope to be challenged.

REFERENCES

[1] Y. Yamazaki, *eds*, Accelerator Technical Design Repor for High-Intensity Proton Accelerator Facility Project, J-PARC, KEK-Report 2002-13; JAERI-Tech 2003-044.
[2] M. Kinsho, in this proceedings.
[3] N. Hayashi et al, “Development of the beam diagnostics system for the J-PARC Rapid-Cycling Synchrotron”, Proc. of PAC2005, Knoxville, May 2005, p. 299.
[4] N. Hayashi et al, “The beam diagnostics system for J-PARC synchrotrons”, Proc. of HB2006, Tsukuba, May 2006, p.128. (KEK Proceedings 2006-15).
[5] S. Hiroki et al, in this proceedings.
[6] H. Sako et al, in this proceedings.
[7] N. Hayashi et al, in this proceedings.
[8] H. Harada et al, private communications. (injection line with circulation orbit matching)
[9] Hitachi Metals, Ltd.
[10] Bergoz, BDCCT-S-380-H.
[11] K. Yamamoto et al, in this proceedings.
[12] K. Satou et al, in this proceedings.
[13] H. Takahashi et al, in this proceedings.