BEAM INSTRUMENTATION AT THE 1 MW PROTON BEAM OF J-PARC RCS

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Abstract

Rapid Cycling Synchrotron(RCS) of Japan Proton Accelerator Complex(J-PARC) is providing more than 300 kW of proton beam to Material and Life science Facility(MLF) and Main Ring(MR). Last summer shutdown, a new ion source was installed to increase output power to 1 MW. In order to achieve reliable operation of 1 MW, we need to reduce beam loss as well. Beam quality of such higher output power is also important for users. Therefore we developed new monitors that can measure the halo with higher accuracy. We present beam monitor systems for these purposes.

INTRODUCTION

The 3 GeV rapid cycling synchrotron (RCS) at the Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton synchrotron. It delivers an intense proton beam to the target for neutron production in the Materials and Life Science Experimental Facility (MLF) as well as to the Main Ring (MR) synchrotron at a repetition rate of 25 Hz[1]. The RCS commissioning started since 2007, and output beam power was gradually increased. So far, RCS is providing about 300 kW of proton beam to MLF and MR[2]. Last summer shutdown, we installed a new ion source and radio frequency quadrupole linac to achieve designed output power of 1 MW[3]. In the beam commissioning of October 2014, we achieved 770 kW output with acceptable beam loss[4].

In order to achieve reliable operation of 1 MW, we need to reduce beam loss as well. Beam quality of such higher output power is also important for users. Therefore we developed new monitors that can measure the halo with higher accuracy. At first we present beam monitor systems which are used for the beam commissioning to establish higher power operation. Next we introduce some new monitors to measure the beam halo with higher accuracy and to achieve higher reliability.

REGULAR MONITORS FOR BEAM COMMISSIONING

The monitor system is important to conduct the beam commissioning. Figure 1 shows RCS parameters and the monitor location. Some parameters of regular monitors are written in a reference[5].

Beam Position Monitor (BPM)

We prepared 54 BPMs (Normal BPM) to measure a beam orbit in the RCS. Since the physical aperture of the RCS is too large (more than 250mm), it is difficult to ensure the linear response. In order to clear this issue, we chose the diagonal cut electrode[6]. Figure 2 shows the 3-D model of the BPM head. Three BPMs (ΔR-BPM), which are installed in the arc section of the large dispersion function, are used for RF radial feedback system. We also have extra two BPMs (324BPM) which can detect 324 MHz frequency signal. 324 BPM are used to obtain the information of the injection beam[7].

The normal BPM system has two operation modes. The one mode, so-called "COD mode", is to record the averaged beam position of each 1 ms by the full 25 Hz repetition. The other is to store the whole waveform data of all BPMs for further analysis, like turn- by-turn position calculation (not 25Hz but 1 shot per several seconds).

The position accuracy is estimated to be about 0.5 mm using a newly developed Beam Based Alignment method[8].

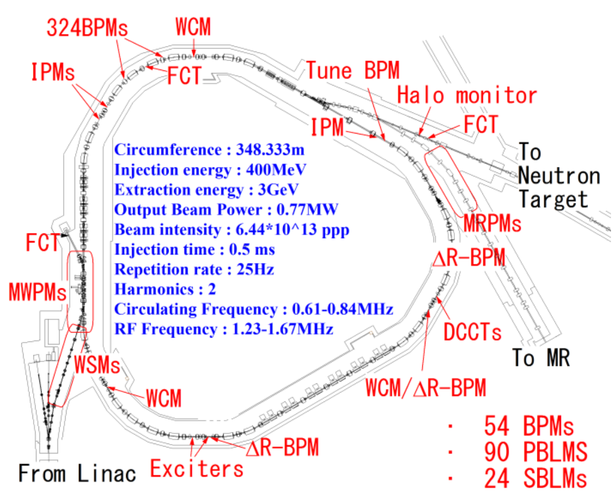

Figure 1: Monitor Layout and RCS parameters.

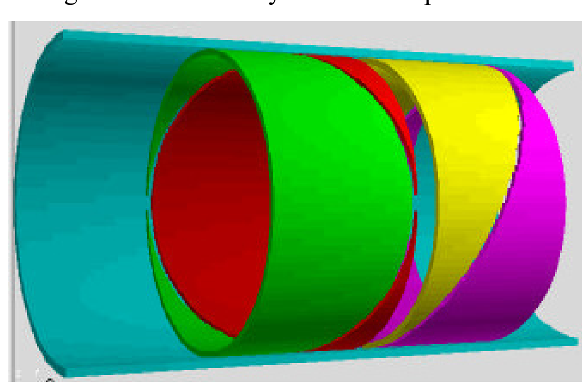

Figure 2: 3-D model of the diagonal cut electrodes.

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Tune Measurement

Transverse betatron tune is one of the important parameter for a synchrotron. To measure the tune value, two exciters and one tune BPM are prepared. Tune BPM has four electrodes for horizontal and vertical tune measurement. Vertical exciter has two electrodes at top and bottom in the vacuum chamber, and horizontal exciter has two electrodes at left and right side in the vacuum chamber. A longitudinal length of exciter electrode is 586mm and an arc length is 200mm. RF amplifiers for the exciters can drive 1 kW RF, and its frequency range is from 100 kHz to 7 MHz. The signal from tune BPM is analyzed by a real time spectrum analyzer and the data is stored in PC. Figure 3 shows the measured and calculated tune during acceleration.

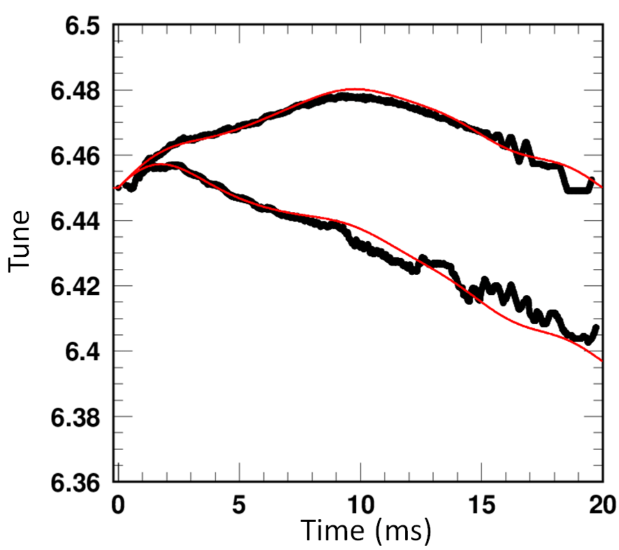

Figure 3: measured and calculated tune during acceleration. Black:measured, Red:calculated

Current Transformer (CT)

We have two DCCTs to measure the beam current during whole acceleration process. First DCCT was purchased from Bergoz[9], and second one was developed. Second DCCT is made by the FINMET. In both DCCT, Dynamic range is from 150 mA to15 A and the bandwidth is DC to 20kHz. Those inner diameters are 380mm. The accuracies are about 1%.

Three fast CT (FCT) are installed. Those are made by the FINMET. The number of the coil turn is 20 and bandwidth is 2 kHz to10 MHz. Two FCT are used to phase detection for RF, and one FCT measures and limits the beam current to the injection dump[10].

The Wall Current Monitos (WCM) are used to measure the longitudinal profile of the beam. We have three WCS. The shunt impedances of WCM is 0.1 ohm (10 ohm*100 para). We can also obtain the longitudinal tomography by the WCM data.

Beam Loss Monitor (BLM)

We prepared two kind of BLM. One is the proportional counter (PBLM) and the other is a plastic scintillator connected on a photo multiplier tube (SBLM).

The filling gas of PBLM is Ar-Co2 mixture, and it was purchased from Toshiba Electron Tube Co., Ltd[11]. A total of 90 PBLMs were set up all over the accelerator beam line. These PBLMs are connected with the machine protection system (MPS) and it is always checking that the integration of PBLM signal is not over a preset value. Integration values are also archived at all times and we can check it when some interlock alerted.

SBLM has good time resolution (FWHM is less than 100ns) and its wave form data is used for a comparison between the experiment and simulation. So far, the time structure and the amount of the beam loss are well in agreement with the simulation.

Ionization Profile Monitor (IPM)

In order to measure the transverse beam profile during the acceleration period, we installed three IPMs as a non-destructive beam monitor. Two IPMs are installed in the dispersive arc section, and one IPM is installed dispersion-free extraction straight insertion.

From the beam test, it found that the external electric field was distorted and the measured beam profile on the ion collection mode was also shrunk to a half [12]. We replaced the electrode, resisters, Micro Channel Plate (MCP) and anode plate. Figure 4 shows New MCP and anode plate. After that the electric field becomes uniform and we can take an beam profile with enough accuracy[13].

Figure 5 shows the IPM measurement result of the injection beam.

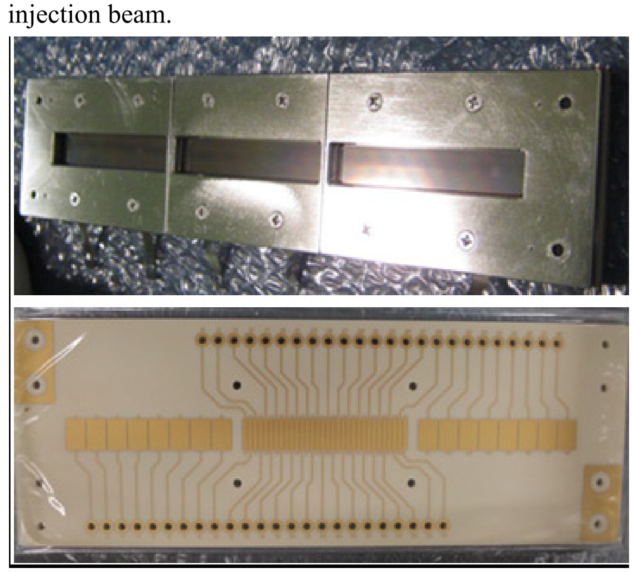

Figure 4: New MCP and anode plate.

Wire Monitors (WSM, MWPM, MRPM)

The destructive profile monitors, Wire Scan Monitors (WSM)[14], Multi Wire Profile Monitors (MWPM)[15]

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and Multi Ribbon Profile Monitors (MRPM)[16] are used at the Linac - 3 GeV RCS Beam Transport (L3BT) line, 3 GeV RCS -50 GeV main ring Beam Transport (3-50BT) line and injection line of RCS. These monitors detect the secondary electron emission from the wires or ribbons. Further information of these monitors is in references.

The MWPM7, which installed in the injection dump line, was used not only to measure the profile, but also to measure the amount of H^0 and H^- unstripped particles. Measurement results are shown in reference[17].

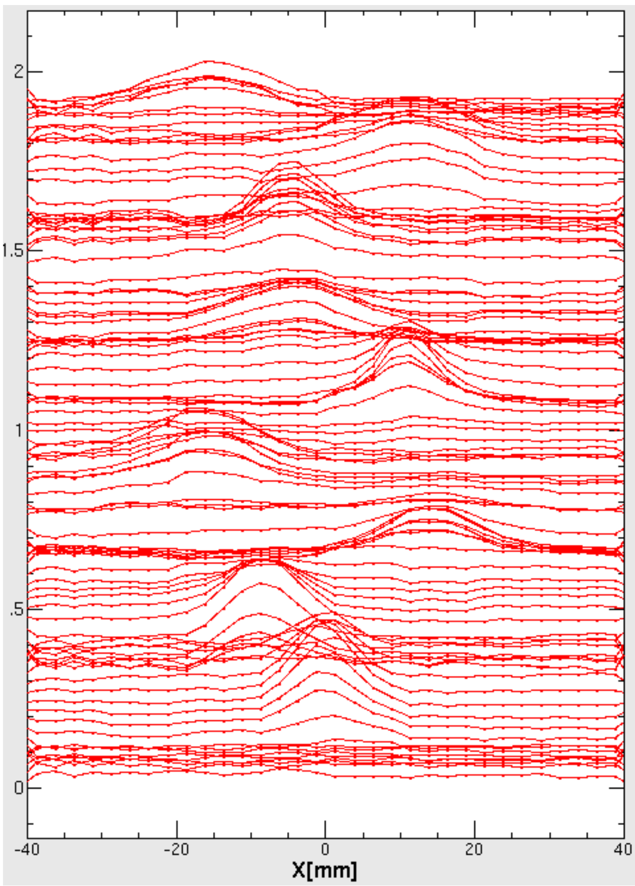

Figure 5: IPM measurement result of the injection beam.

NEW MONITORS FOR FURTHER SAFETY/QUALITY OF THE BEAM

Monitors for Safety/Stable Operation

The radiation leak accident was happened in the hadron experimental hall at J-PARC on May 23, 2013. The accident was caused by a target sublimation due to an abnormal beam extraction from the main ring[18]. From this accident, we think we have to improve the monitoring systems and interlocks to prevent and rapidly detect the radiation leakage. In the RCS, we installed two new systems. First one is the real time monitoring system of the beam profile on the mercury target. In this system, we can check the beam profile on the mercury target by multi wire monitor when some interlock alerts. Figure 6 shows the measured profile on the mercury target. Second new system is fast interlock of linac CT. In this new interlock, the beam is stopped immediately when the beam current exceed the limit.

These new systems provide us more safety and stable operation.

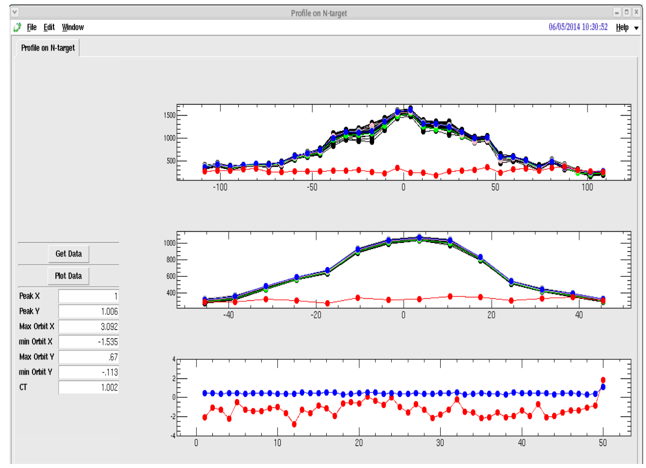

Figure 6: The beam profiles on the mercury target.

Injection Beam Halo Monitors

The halo of the injection beam is a source of the beam loss in RCS. We tested two kind of monitors to measure the injection beam halo[19]. The one is the Vibration Wire Monitor (VWM), and the other is the monitor by using the L3BT scrapers, SBLM and CT.

The VWM was purchased from Bergoz. The principle of the VWM is to detect the eigen frequency shift that induced by the temperature rise due to the beam hitting of the wire. The wire is made by sus316L and its diameter is 0.1mm. We tested VWM to measure injection beam profile, but we cannot take data at some frequency regions. We think perhaps electric circuit has some problem and now we try to improve it.

The schematic of the halo monitor system by L3BT scraper is shown in Figure 7. The L3BT scrapers are located downstream in the linac. The J-PARC linac accelerates negative hydrogen beam for the charge-exchange injection of RCS. The L3BT scraper removes two electrons from the negative hydrogen, and scraped halo beam that was converted to the proton is transported to the 100 deg. dump. Therefore we can measure the amount of the scraped halo beam by the SBLM located near the scraper. A beam current of the scraped halo beam is also measured by the CT at the 100 deg. dump line. This system has two advantages. The first advantage is the redundancy by two kind of monitors which measures in another principle. The second advantage is absolute value measurement by the CT. In the usual case, the amount of the halo is measured as a relative value of the amount of the core beam. But this system can directly measure the amount of the halo. Figure 8 shows the measurement result of this system. Measured results are consistent, and the SBLM and the CT are able to detect

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the halo of ten to the minus fourth power order of magnitude to the core beam.

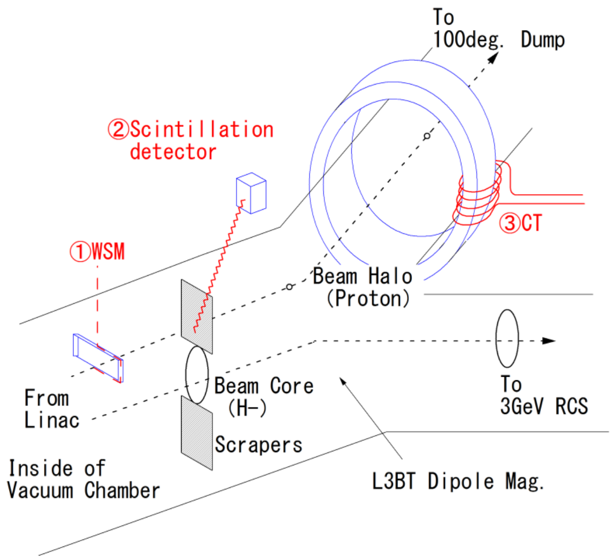

Figure 7: Schematic of the monitor system by the L3BT scraper.

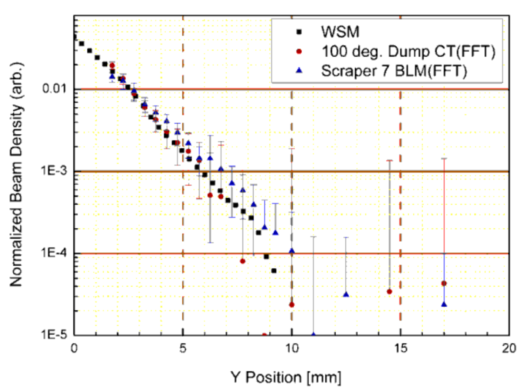

Figure 8: Measurement results of the monitor system by the L3BT scraper.

Extraction Beam Halo Monitors

Two kinds of monitors were developed to reduce the beam loss of MR by the halo of the RCS extraction beam.

The first one, Optical Transition Radiation (OTR) monitor, is installed in the 3-50 BT line. To achieve a large dynamic range, a multi-screen system is adopted. By using this system, the halo of ten to the power of minus six to the peak of beam core can be observed[20].

The second monitor is similar to L3BT scraper system. This system consists of a wire type beam scraper and some beam loss monitors. To use some kinds of SBLM with different sensitivities, it has wide dynamic range. Beam profile including both of the beam core and halo can be measured.

Measurement results are shown in references[21][22].

Delayed Proton Monitor for μ-e Conversion Measurement

DeeMe (Direct electron emission measurement for Mu-e conversion) experiment, proposed at MLF, is planned to find μ-e conversion process on the muon production target[23]. In order to distinguish the μ-e event signal from a background, the number of delayed protons (we call such delayed proton "after-proton") that come after hundreds of nanoseconds from the main beam should be less than ten to the power of minus eighteen order of magnitude. This corresponds that only few after-protons are allowed within 1 hour operation. Figure 9 shows the measurement time window of DeeMe. It is impossible to measure such slight protons by an ordinary monitor. Thus, in order to develop a new measurement system for the background evaluation, we considered what particle becomes the after-proton.

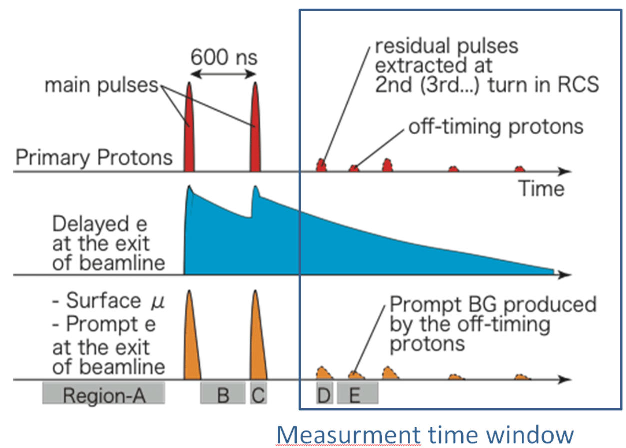

Figure 9: Measurement time window of DeeMe.

If the after-proton exists, the proton have to remain after extraction of the two main bunches and it needs to extract without the pulse kicker magnetic fields. This fact means that the after-proton must have extremely larger emittance than the normal beam. Orbit calculation result indicated that the protons with 2500 πmm-mrad. emittance can partially extract, and some particles hit the branch chamber in that case. Therefore we can detect the existence of the after-proton by monitoring the protons that are scattered at the branch chamber.

We simulated scattered proton trajectories by G4Beamline code[24]. Here we assumed from 324π to 5000π mm-mrad. emittance uniform beam. Figure 10 shows the geometry and the proton trajectories in the simulation. The simulation result showed that the ratio of the number of the proton that hit the outside scintillators (two green plates in Fig. 10) to the number of the proton that pass through the 3NBT line is 0.025. We set up two SBLMs like the simulation model, and measured the scattered protons. Measurement was carried out from Mar. 7, 2013 to May 25, 2013. During this operation period, the total coincident counts in the time window are 87. On the other hand, total extracted protons are

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$3.13*10^{21}$. By using these values, we can obtain the after-proton rate of $1.1*10^{-18}$. This almost satisfies the requirement.

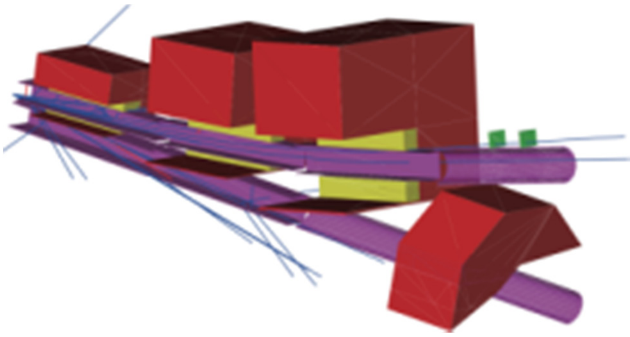

Figure 10: simulation result of after-proton.

CONCLUSION

We demonstrated 770 kW beam in October 2014. Since regular monitors worked well, so far we understand the characteristics of the beam. Since regular monitors worked well, so far we understand the characteristics of the beam. To establish further stable and safety operation, some monitors and interlocks are improved. To reduce the beam loss, high sensitive halo monitors are developed.

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