

BEAM PROFILE MONITOR OF THE J-PARC 3 GeV RAPID CYCLING SYNCHROTRON

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Abstract

To obtain high intensity (1MW) and large emittance (214π mm·mrad) beam profiles of the 3 GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC), residual gas ionization profile monitors (IPMs) with wide active aperture and high dynamic range have been developed. It has three Microchannel Plates (MCPs) with active area of 81×31 mm for signal multiplication and read out devices, and magnet system to generate guiding field to collect electrons. The wide active aperture of ± 116 mm is obtained by arranging the three MCPs perpendicular to the beam axis. Furthermore, the dynamic range of 10^4 level can be obtained by adjusting each bias voltage of the MCPs. The IPMs are now collecting ions without guiding field.

The beam commissioning of the RCS has been in progress since last year. The horizontal and vertical profiles are of great help particularly to check injection errors. In this paper, the present status of the IPM system and the latest beam profiles are reported.

INTRODUCTION

The accelerator series of J-PARC is composed of 181/400 MeV Linac, 3 GeV RCS, and 50 GeV MR (Main Ring) Synchrotron [1]. The Linac accelerates the H^- beams up to 181 MeV at the first stage, and then will be upgraded to the maximum energy of 400 MeV at the second stage. The Linac beams are delivered along the L3BT beam transport line to the 3 GeV RCS. After transform the H^- into proton beams, the RCS accelerates these up to 3 GeV within 20 ms. An operation frequency of the RCS is thus 25 Hz. The extracted beams are for a neutron target of Materials and Life Science Facility and for the 50 GeV MR.

Circulating beams ionize residual gas and electron-ion pairs are generated along beam trajectories. The density distribution of the charged particles are relative to the beam density, thus projection of the charged particles by an external electric field perpendicular to the horizontal and vertical axis shows one dimensional beam profiles. Both the electrons and ions can be used, although the precise electron collection requires the guiding magnetic field.

The first design study of the IPM for the J-PARC RCS was reported by Lee *et al.* [2]. To check basic performances, a prototype with magnet system was developed and tested at KEK-PS [3, 4]. A profile distortion due to

strong electric fields originating from circulating beams which deflects trajectories of collecting charged particles was investigated.

REQUIREMENTS FOR A PROFILE MEASUREMENT

The characteristics of the RCS beam are high intensity and large emittance. The maximum beam intensity is expected to be 4×10^{13} ppb which corresponding to the beam power of 1 MW when 2 bunches 25 Hz operations are made. The maximum beam emittance is expected to be 216π mm·mrad; large active area of ± 50 mm are required.

High power beam acceleration requires nervous control of beam loss. On the viewpoint of activation controls of the accelerator components, the beam loss power should be restricted to that lower than a several watt per meter. This means that a beam loss ratio is restricted to be that less than 0.04 % \sim 0.6 % depending on the beam energy. To control beam loss such a rare event and to study beam loss mechanisms, not only to measure a beam core profile but also to measure a beam halo region are required. The dynamic range of 10^4 level is likely to be required for 1 MW operations, although it depends on the beam shape.

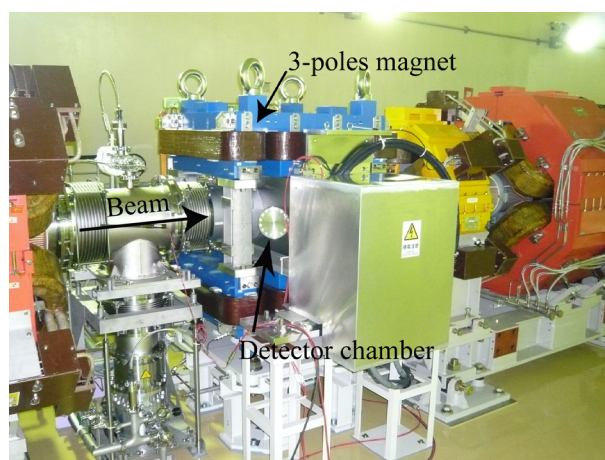


Figure 1: Photograph of the horizontal IPM.

OVERVIEW OF THE IPM SYSTEM

Two IPM systems, horizontal and vertical, are installed in the first arc section of the RCS ring. The betatron amplitude and the dispersion at the horizontal IPM (H-IPM)

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are, $\beta_x = 10.36$ m, and $\eta_x = 3.91$ m, respectively, and betatron amplitude at the vertical IPM (V-IPM) is $\beta_y = 11.73$ m. The $\Delta p/p$ is $\approx 0.1\%$. Another IPM system will be installed at the second straight section where the dispersion is zero. The figure 1 shows a photograph of the H-IPM.

Each IPM is composed of three micro channel plates (MCPs) [5] as charge signal multiplication and signal read out devices, three electron generator arrays (EGAs) [6] as electron sources to check gain valances of the MCPs, electrodes for high voltage feeder, and 3-poles magnet system to feed guiding field.

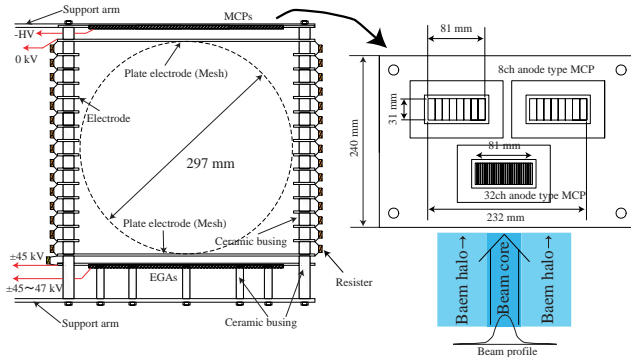


Figure 2: Schematic drawing of the inside of the detector chamber and the arrangement of the three MCPs.

Fig. 2 shows the schematic drawing of the inside of the detector chamber. The MCPs and EGAs are lined perpendicular to the beam axis as shown in the figure. Consequently, the active aperture is thus ± 116 mm. Here, the two types of MCPs are used. The central one is a 2 stage MCP assembly with 32 ch anode strips. The dimension of each strip is 2.5 mm in width and 31 mm in long. On the contrary, the side MCP has 8 ch anode strips, here the dimension is 10 mm in width and 31mm in long. The typical gain of the MCP is 10^6 for each anode strip.

The maximum HV on the electrode with EGAs is 45 kV. The voltage is divided and applied on each pillow like electrode by 100 M Ω resistors.

The signals from MCPs are amplified by the preamplifier and then are AD converted by the oscilloscopes. The capacitance of the coaxial cable from the detector output to the preamplifier input is about 1nF. At present, the input impedance of the preamplifier is set as 1 k Ω , thus the raw signal from the output of the preamplifier has decay constant of 1 μ s. Each signal from the preamplifier is averaged over arbitrary shot number at the oscilloscope. The sampling frequency is set as 20 MS/s.

The Fig. 3 shows the distributions of the magnetic fields of the 3-poles magnet. The magnets were designed such that the line integral value of the magnetic field along the beam axis is zero so as not to kick the circulating beam. As can be seen in the figure, the calculated vertical field B_y well reproduces the measured one. The flatness of the B_y

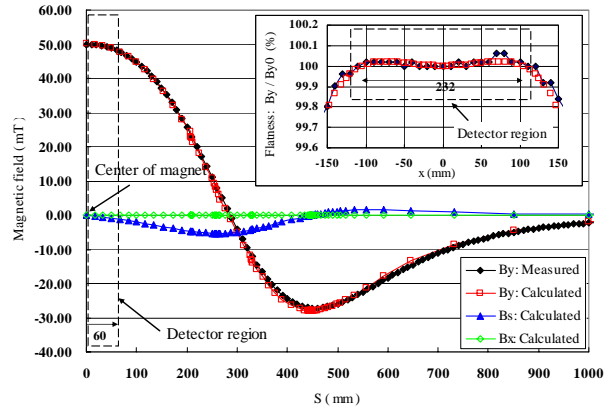


Figure 3: Measured and calculated magnetic fields along the beam axis. The inside view shows the flatness of the vertical magnetic field (B_y) along the horizontal axis with magnet center. The dashed-line boxes are eye guide of the area where the detectors are mounted. The origin of the coordinate is the center of the IPM.

in the area of interest, that is the detector area, is $\pm 0.05\%$ along the horizontal axis and $\pm 2\%$ along the beam axis.

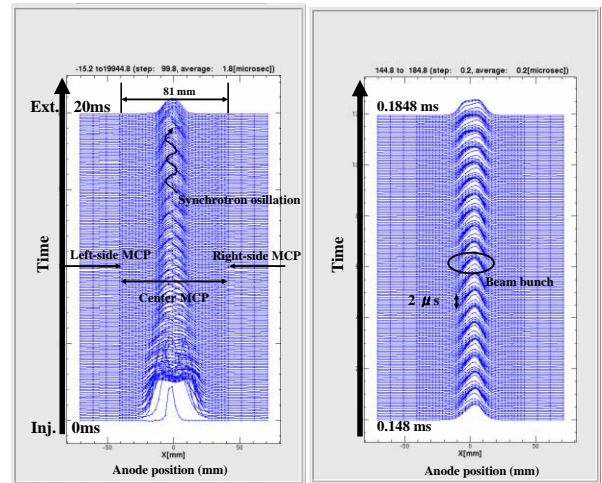


Figure 4: Mountain views of the horizontal profiles measured by collecting ions. The left hand side figure shows a series of profiles from injection to extraction. The right hand side figure, which is an expanded view of the left one, shows turn by turn beam profiles. The outermost 8 signals from the two side-MCPs are not shown only for an enlargement of the transverse axis.

TURN BY TURN PROFILE MEASUREMENT

Profile Measurement Using Ions

As mentioned in the previous section, 10 slice profile data are obtained during 1 revolution period at 3 GeV. The Fig 5 shows a mountain plot of turn by turn horizontal profiles averaged over 110 shots, where the beam bunches from the Linac were center-injected. These were measured by collecting ions with applied HV of 30 kV. The beam intensity was 4×10^{11} ppb, and the residual gas pressure was about 1×10^{-6} Pa.

Averaging reduces high frequency noise and also reduces signal fluctuation due to the statistical error of the number of the collecting ions. An estimated number of the collecting ions per 1 anode per 1 bunch is about 50. Thus averaging over 110 shots reduce the statistical error down to 1.3 %.

Since the H-IPM is at the arc section, as shown in the left hand side figure, the fluctuation of the beam center due to the synchrotron dipole oscillation is shown. The beam size fluctuation, seen in the right hand side figure, is due to the synchrotron quadropole and the betatron oscillation.

The dependence of the beam size on the applied HV was measured for the case of the center injection. The beam size was extracted from the profile just before the extraction assuming that the obtained profile is Gaussian like distribution. Fig. 5 shows the extracted standard deviations. Above the 20 kV, the measured beam size is saturated. Actually, the 1 MW beam acceleration will be operated with painting injection.

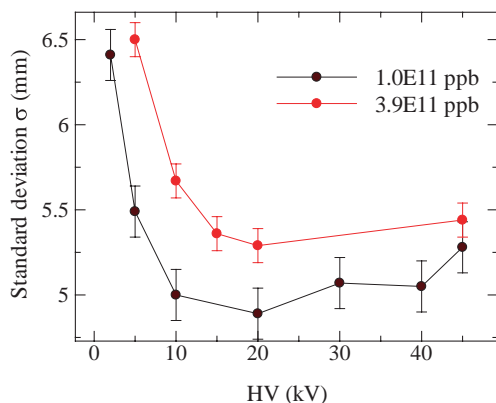


Figure 5: Dependence of the measured beam size on an applied HV. Each beam size was extracted from a measured profile, which is assumed to be Gaussian distribution, just before the extraction.

Profile Measurement Using Electrons

The profile measurement using electrons with guiding magnetic field was tested. However the measured profile

was considerably distorted. The cause of the distortion is now under investigation.

CONCLUSIONS AND SUMMARY

The IPM have been developed to measure high intensity beam profile with large beam size of about ± 50 mm. The three MCP detectors are used to cover such a large aperture. The two IPMs with 3-poles magnet were installed at the first arc section and shows the good performance for the case of the ion collection mode for the present beam intensity.

Turn by turn beam profiles were obtained in good signal resolution by averaging over about 100 shots. A typical signal to noise ratio is about 100. Therefore, by adjusting the gain of each MCPs the dynamic range of 10^4 level can be obtained.

The electron collection with guiding magnetic field was also tested, however it shows distorted profiles. The fringe electric field of the HV electrodes in the detector chamber may be the cause of the distortion. Further investigation on the problem is needed to measure the 1 MW high intensity beam profile.

REFERENCES

- [1] JAERI-Tech 2003-044 Accelerator Technical Design Report for High-intensity Proton Accelerator Facility Project, J-PARC.
- [2] S. Lee, *et al.*, Design Study of a Nondestructive Beam Profile and Halos Monitor Based on Residual Gas Ionization for the J-PARC RCS, Proceedings of the 14th symposium on accelerator and Technology, Tsukuba, Japan, Nov. 2003.
- [3] K. Satou, *et al.*, A Prototype of Residual Gas Ionization Profile Monitor for J-PARC RCS, Proceedings of the EPAC 06, TUPCH065.
- [4] K. Satou, *et al.*, Developments of Residual Gas Ionization Profile Monitors for J-PARC RCS and 50 GeV MR, Proceedings of the 3rd Annual Meeting of Particle Accelerator Society of Japan and the 31th Linear Accelerator Meeting in Japan (2006) (in Japanese).
- [5] Internal technical report of MCP by Hamamatsu Photonics, Inc., <http://jp.hamamatsu.com/en/>
- [6] ELECTROGENTM, the electron generator array made by BURLE Electro-Optics, Inc., <http://www.burle.com>.