DEVELOPMENT OF THE BEAM HALO MONITOR IN THE J-PARC 3-GeV RCS

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Abstract

Transverse beam halo is one of the most important beam parameters because it limits the performance of a high intensity beam accelerator. Therefore in the J-PARC 3-GeV RCA, transverse beam halo measurements are required to increase the output beam power. Transverse halo monitors, which are horizontal and vertical scanning aluminium plats type, have been installed in the extraction beam line. But the residual free electrons hindered the beam halo diagnostic. Thus we combine the several devices and methods to measure the beam halo components. And then various new transverse beam halo monitors are developed to measure the beam halo more clearly.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) has been beam commissioned for initial beam tuning tests since October 2007[1] and afterwards we started user operation for the Material and Life science experimental Facility (MLF) and the 50-GeV Main Ring synchrotron (MR). Since December 2009, we have started a beam tuning for high-intensity beams [2], and up to now we successfully demonstrated a 420kW beam operation. In order to provide such a high intensity beam for user operation, it is required to improve the quality of the extraction beam by finer beam tuning in the RCS.

One of the key parameters to evaluate the beam quality is the transverse beam halo. In generally, the beam halo quantity is less than 10^{-4} of the beam core. Therefore halo measurements require ultra wide dynamic range, high sensitivity and resolution, and noise rejection techniques of instruments and methods. In the case of the RCS, the charge-exchange multi-turn injection with the stripping foil and fast extraction system with the kicker magnets are adopted. Thus the injection beam is consisted of negative hydrogen ion (H^-) and shaped into the intermediate pulses by the RF chopper. On the other hand, extraction beam is two bunched proton (H^+) beam. We can obtain the injection and extraction transverse beam haloes respectively by combining various devices and method. At the same time, some technical issues are found in the beam halo measurements. In this paper, we describe the transverse beam halo measurement and introduce some developing new halo monitors.

STRIPPING FOIL + DCCT

In order to measure the injected H^- beam position and profile, the RCS has seven multi-wire profile monitors (MWPM) at the injection area [4, 5]. The MWPM is one of the very useful and powerful tools for the beam commissioning. But available beam intensity is limited to prevent the thin sensor wires from cutting off, thus it cannot be measure high intensity H^- beam profile directly. All MWPMs are installed near the horizontal shift bump magnets which generate a huge noise. But MWPM does not have some noise rejection technique. Figure 1 shows the typical measured H^- beam profile at the injection point with the MPWM4. Red line is plotted by measured MWPM data and black line is a Gaussian fit to the beam core components. As a result, the beam core and beam tail can be obtained clearly, but it is difficult to distinguish the beam halo components from the measured profile by the MWPM.

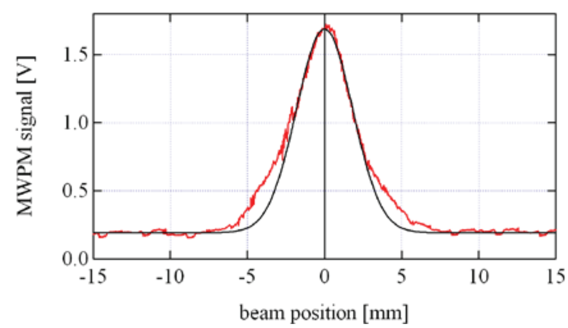

Figure 1: Measured H^- beam profile at the injection point with the MWPM4.

As another method of the injected H^- beam profile measurement, the RCS adopts the foil scanning [5]. The stripping foil position is scanned while the DCCT signal data are acquired, and then the profile can be obtained by differentiating the DCCT data. At first the foil scanning method is aimed to search the beam irradiation spot at the foil, but we appreciated that this scheme has high dynamic range and can measure the high intensity beam profile directly. The DCCT has three current ranges, 0.15A, 1.5A, 15Ampere full scale, and has measurable dynamic range of 10^{-2} on each current range. Thus total dynamic range of 10^{-5} is achieved by changing the current range. The injected H^- beam profile and halo can be measured by the foil scanning method as shown in figure 2. Red open circles are differentiating the DCCT data and black solid line is Gaussian fit to the core components of the DCCT data. This plot shows clearly that the measured profile has two different slops due to the beam tail components at the range of 10^{-1} to 10^{-3} order and the beam halo component at the range of 10^{-3} to 10^{-5} order.

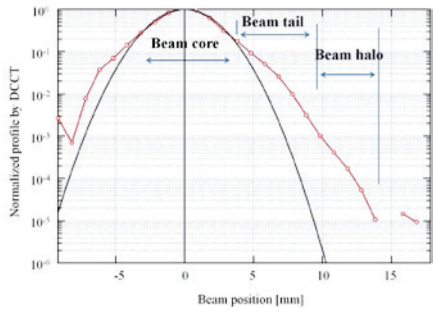

Figure 2: Measured H⁻ beam profiles by the foil scan method. Two different slops show the beam tail components and the beam halo components respectively.

The measured beam profile by foil scanning method is asymmetrically as shown in figure 2. In the case of the charge-exchange multi-turn injection scheme, the more the foil is inserted into the beam deeply, the more the circulating beam intensity is lost due to the foil scattering beam losses. Then we develop the new beam halo monitor using the vibrating wire scanner (VWM) [6]. Now we started the offline study for the VWM in the test stand with low energy electron gun, and an electron beam profile can be obtained successfully. The VWM for injection beam will be installed in this summer.

HALO SCRAPER + S-BLM

An extraction transverse beam halo monitor was installed at 3GeV RCS to Neutron source Beam Transport line (3NBT). The extraction halo monitor is the scraper type as shown in figure 3. The halo monitor has two aluminium plates with thickness of 0.1mm and wide of 60mm, and a secondary emission current of the each plate can be read out. These plates can be scanned along the horizontal and vertical axis respectively. The horizontal plate scrapes the extraction beam from the outside and the vertical plate scrapes one from the underside, but both two plates stop at the beam center. The available scanning range of this halo monitor is limited to stave off any damage of the plate by heating. Thus only half profile is obtained in principle. Furthermore the secondary emission current signal read out the plate includes the huge noises. The sources of these huge noises are some EM noises from the AC magnets, residual free electrons in the vacuum chamber, and so on. It was difficult to reduce these noises in spite of any noise counterplans.

In order to measure the transverse extraction beam halo, we combine a Scintillator-photomultiplier type Beam Loss Monitor (S-BPM) with this scraper type beam halo monitor. The S-BLM is fixed on the outside of the halo monitor's vacuum chamber and measures the amount of the radiation due to the beam loss created at the scraper plate. The S-BPM has high sensitivity and rapid responsibility [7, 8]. Thus a few particles in the beam halo can be measured by the S-BLM and the measured signal keeps a longitudinal bunched beam structure as shown in figure 4. However it is also sensitive to other sources of any beam losses. This background signal can be measured by the same S-BLM while the scraper plates were retraced and the extraction beam does not hit them. Thus the real beam halo signal can be obtained by subtracting the background signal from the measured one. Figure 4 shows the typical results of this subtracting method.

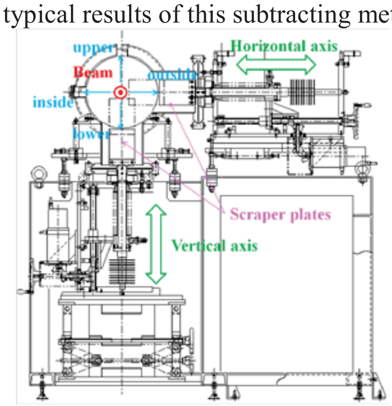

Figure 3: Schematic diagram of the extraction transverse beam halo monitor.

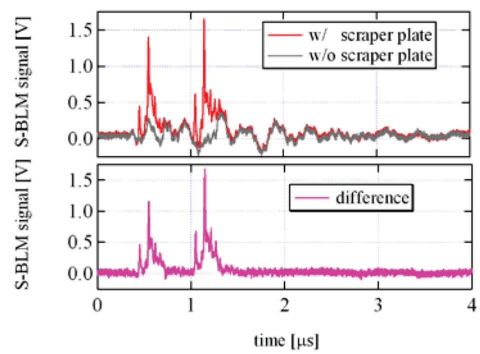

Figure 4: Typical measured signals of the S-BLM. Red line and gray line in upper graph are the measured S-BLM inserted of retracted the scraper plate respectively. Under plot is obtained by subtracting the gray line from the red line.

In order to estimate the beam halo quantity, the S-BLM needs calibration by controlled beam losses at the scraper plate. Due to the limitation of its scanning range, it is not possible that whole particles hit to the scraper plate while the extraction beam passes through along the design orbit. Then, the horizontal local bump orbit of about 20 mm is produced by some steering magnets at the 3NBT line and we verified that whole particles can hit the scraper plate. To calibrate the S-BLM signal for the halo measurement, the beam intensity is cut off by the RF chopper and reduced to less than 10^{-5} of the full beam intensity. The beam intensity with RCS output beam power of 420 kW is 3.5×10^{13} particles par pulse (ppp), thus the target for the calibration is about 1×10^{8} ppp. Figures 5 show the S-BLM calibration results. The ultra low beam intensities can be measured by fast current transfer (SCT) at the linac and the S-BLM signals are measured in changing the bias high voltage (HV). The integrated S-BLM signal as a function of the HV value is plotted in the left graph in the figure 5 and it shows good linearity in such ultra low intensity. The right graph shows correlation between the integrated S-BLM signal and the beam loss particles measured by the SCT, and that means the S-BLM calibration curves for beam halo measurement in each HV.

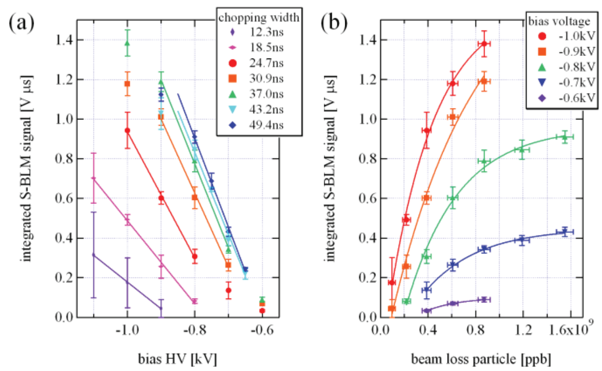

Figure 5: Measured results of the S-BLM calibration data.
(a) As a function of the S-BLM bias HV,
(b) As a function of the beam loss particles.

The method by combining the S-BLM with the halo scraper has a high sensitivity to ultra low intensity beam thus beam halo quantification can be achieved. But its dynamic range is very narrow due to saturation of the S-BLM. In order to obtain the extraction beam profile including both of the beam core and halo, some additional devices will be installed in this summer. Not only the scraper plates but also the single wires are used to generate the beam loss and the several BLMs with various sensitivities are set to achieve the wide dynamic range.

BEAM HALO EXPERIMENT

In the current extraction beam halo measurement scheme cannot be obtained the beam profile. But beam halo quantification is the useful tool for our high power beam commissioning. One restriction on the high power beam operation at the MR is a collimator limit at the 3GeV RCS to 50GeV MR Beam Transport (3-50BT). The 3-50BT collimator aperture is 54π, thus we aimed the beam halo components defined by particles at the outside of the 54π aperture to suppress as possible. In the recent beam commissioning, finer beam tuning to suppress the beam halo components in the RCS is carried out [9, 10]. In the last section, we introduce the outline of the beam halo experiment with the output RCS beam power of 420kW. The halo scraper plate was set at the edge of the 54π beam emittance decided by lattice measurements at the 3NBT line [11]. By using several transverse and longitudinal beam painting schemes as beam tuning knobs, the halo components can be obtained as shown in figure 6. We can judge an available beam operation scheme by seeing such a trend of measured beam halo components.

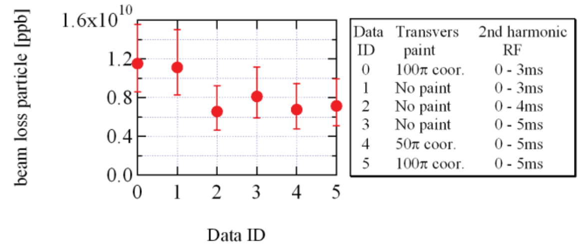

Figure 6: Experimental result of extraction beam halo measurement by changing the injection painting scheme. The more detail is shown in ref. [9, 10].

SUMMARY

Transverse beam halo is one of the most important beam parameters, and the beam halo measurement is key issue for a high power proton accelerator like the J-PARC. In the RCS, the injection and extraction beam haloes are measured by combining various devices and methods. The injection beam halo which is less than 10^{-4} of the beam core can be measured by combining the DCCT with stripping foil. The extraction beam halo quantification can be achieved by the S-BLM with the halo scraper. This method can measure the beam halo components with ultra low intensity of about 1×10^{8} ppp.

Through the halo experiments, we found some technical issues. In the future plan, we develop new halo monitor. For the injection beam halo measurement we will try the VWM and now the offline study at the test stand with low energy electron gun are started. Extraction beam halo monitor have to obtain the beam profile including both beam core and halo. Thus additional devices which are single wires and various sensitivity BLMs are developed.

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