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MULTI-RIBBON PROFILE MONITOR FOR HIGH POWER PROTON BEAM AT J-PARC MR ABORT LINE

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Abstract

Japan Proton Accelerator Research Complex (J-PARC) Main Ring (MR), the world-class high intensity proton synchrotron, provides proton beam to two experimental facilities with two extraction modes: Fast extraction (FX) and Slow extraction (SX). The number of protons per pulse (ppp) in MR recorded the world highest value of 2.7×10^{14} in the FX mode. Now we are planning to increase the ppp further up to 3.3×10^{14} in near future. The beam profile is one of the most important parameters to discuss the high intensity beam dynamics in MR. Monitors using multi-wires / ribbons are effective to measure the beam profile with good accuracy and wide dynamic range. However, they cause significant beam losses by interactions with high-intensity circulating beam in synchrotrons. Recently, we installed new multi-ribbon profile monitor (MRPM) in an abort line in MR. The abort line is one of the extracted beam lines of the FX system. It has a quadrupole doublet which is called Abort Q and transports extracted beam to a beam dump. The FX system can extract the circulating beam in MR with an arbitrary energy. Performing the single-pass measurement with MRPM and changing the transfer matrix by sweeping field strength of Abort Q, the emittance of the extracted beam can be measured. In this paper, we present the design, manufacturing, and results of the first beam test of newly installed MRPM system.

INTRODUCTION

J-PARC MR, the high-intensity 30 GeV proton synchrotron, provides proton beam to two experimental facilities, the hadron experimental hall by the slow extraction (SX), and the neutrino beam line by the fast extraction (FX). The number of protons in the FX mode records 2.6×10^{14} ppp. The mid-term goal of MR is to deliver 1.3 MW beam intensity to the neutrino beam line by shortening the repetition time together with increasing the number of ppp up to 3.3×10^{14}. To achieve the beam power, hardware upgrade is now in progress for magnet power supplies, RF systems, collimators, injection and FX extraction systems, and so on as described in [1]. From the view point of high intensity beam dynamics in the upgrade plan, the beam emittance is one of key parameters to maximize the performance and efficient commissioning of MR. The beam profile monitoring with good accuracy and wide dynamic range is important to measure the emittance. In March of 2019, the new profile monitor called Abort Multi-Ribbon Profile Monitor (Abort MRPM) was installed in the abort beam line which has an absorption capacity of 7.5 kW. It is the first beam profile monitor installed in the abort line in MR. The FX system in MR can extract the circulating beam with an arbitrary energy. Therefore, the Abort MRPM makes possible to measure beam profile at the arbitrary energy from 3 GeV to 30 GeV. In addition, the measurement in Abort MRPM does not affect MR circulating beam. This feature of location allows us to perform beam study effectivity.

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DESIGN CONSIDERATION

Abort Line

The abort line is one of the branched beam lines in the FX system of MR. The FX is a bipolar system and can bend the extraction beam from MR both inside to the neutrino beam line, and outside to the abort beam line. The kicked beam to Abort line goes through a quadrupole doublet (Abort Q), Abort MRPM, and finally absorbed at the beam dump as shown in Fig. 1. For the use of the emittance/dispersion measurement which is known as the Q-scan method, MRPM was installed at the downstream of Abort Q. To extend the field tunability of Abort Q, a high power polarity switch was installed to the power supply.

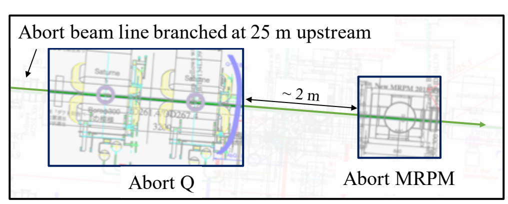

Figure 1: Abort MRPM location.

Chamber and Linear Actuator

The vacuum chamber consists of a main chamber and a linear actuator which is supported with three guides as shown in Fig. 2 (a). Main chamber is made of the stainless steel called SUS304 and the size is $600 \times 600 \times 1000$ mm^3. The multi-ribbon of target module should be removable from beam orbit easily. The target is set off-line in the routine user operation and it is inserted to the orbit position in the accelerator study. For this purpose, the linear actuator

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is equipped with 450 mm bellows.

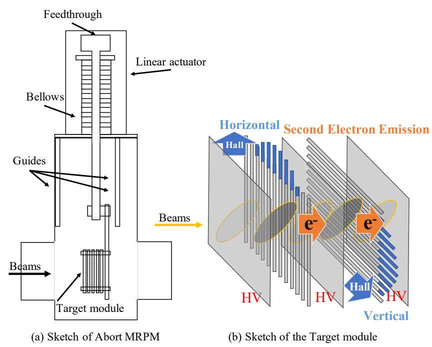

Figure 2: Sketch of Abort MRPM (a) and its target (b).

Target Module

The target, shown in Fig. 2 (b), consists of the multiple Titanium ribbons set in a grid both in horizontal and vertical directions, and Titanium foils is applied high voltage for collection of emitted electrons from the ribbons and also from foils themselves. The electric holes generated with the emitting secondary electrons by the interaction between proton and Titanium ribbon are measured as voltage gain. By reconstructing voltage signals of all ribbons, proton beam profile can be obtained. Applying high voltage around ribbons, any electrons emitted from ribbons and foils can not reach to ribbons, and background signals from the emitted electrons can be kept sufficiently low. In the case of the multi-ribbons, larger transverse surface area is advantageous compared to the case of multi-wires. Abort MRPM is required to measure the beam profile not only in the beam core region but also in the beam halo region. To obtain higher voltage gain in the halo measurement, large transverse surface area is preferable. In addition, for ensuring target durability, ribbon with low volume is required. In the interacting with high-power proton beam, metallic materials are heated by a spallation reaction. In order not to pile up thermal load too much, large surface area with low volume shape, that is the thin ribbon shape is preferable. The Ti ribbon with 1.2 μm in thinness has been adopted to target module. For the measurement with appropriated voltage gain, the ribbon width has to be changed between beam core region and halo region.

Beam Optics Calculation

The ribbon configuration for horizontal and vertical targets was determined by an optics calculation using SAD [2]. The width of the ribbons for the beam core and beam halo were determined to be 1.5 mm and 2.5 mm, respectively. All width of blank space between ribbons were set to 1.0 mm. Said 2.5 mm spacing for core region sand 3.5 mm spacing for halo region, core region is needed to cover narrowest beam and halo region is need to cover the wider beam. The calculated beam size of SX 3–30 GeV and FX 3GeV optics were taken into account to fix the ribbon configuration. In the lattice model of Abort line, ideal magnetic rigidities of FX kicker magnets and septum magnets are adopted ignoring off-axis effects. The momentum spread is fixed to be 0.3% $\sim 3\sigma$. Initial emittance was set to 0.32 π mm·mmrad for the SX 30 GeV beam. Others initial emittance values were obtained by multiplying by factors assuming the adiabatic damping effect. The field strength of Abort Q was set to be the value of current 500 A with polarity. The results are shown in Table 1. The 1σ of the horizontal and vertical minimum beam size was 8.47 / 3.01 mm, and those of the maximum was 28.08 / 16.63 mm. For the core region, the number of ribbons was determined to cover at least 6σ of the minimum value (50.82 / 18.06 mm). For the halo region, 6σ of the maximum value (168.48 / 99.78 mm). Horizontal beam size was expected to be larger than that of vertical, therefore numbers of channel are determined to 67 for horizontal and 33 for vertical. Assigning 67 / 33 channels to cover the horizontal / vertical core and halo region, ribbon spacing was determined as showed in Fig. 3.

Table 1: Calculated Beam Width at MRPM

Ext. Mode	Polarity	H. 1σ (mm)	V. 1σ (mm)
FX 3GeV	+	28.08	8.96
	-	16.63	13.67
SX 3GeV	+	24.62	6.18
	-	14.70	9.39
SX 8GeV	+	15.70	4.97
	-	12.82	5.88
SX 30GeV	+	8.96	2.87
	-	8.47	3.01

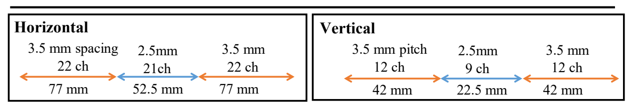

Figure 3: Ribbon spacing.

DAQ System

The data acquisition (DAQ) board called CAVALIER II [3] was installed in the system. The specification of CAVALIER II is listed as Table 2. It is 16 ch VME board which comprises amplifier, 12 bit 250 MS/S AD module, FPGA and Ethernet module, and has an advantage of high repetition rate by using Pipeline ADC. The effective number of bits is 10.5 (~65 SINAD). Six boards are set up for covering 96 channels.

Table 2: CAVALIERII Specification

Read out	Ethernet
Sampling frequency	250 MHz
Sampling time	8 < μs
ADC	12 bit
Gain	1 (adjustable)
Low-pass filter cutoff frequency	None (adjustable)
High-pass filter cutoff frequency	125 MHz

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TARGET MODULE DEVELOPMENT

The target frames is made of baked aluminum board with printed circuit of AgPt. The Titanium ribbons are cut by green YAG laser from 1.2 μm thin foil as described in the preceding study of MRPM [4]. The foils were cut to the 2.5 or 3.5 mm spacing. Since Titanium foil was very thin, it is burned out easily by applying the laser. To avoid burning out, the Titanium foils are cut under Argon atmosphere. Figure 4 shows the horizontal target flame after removing cut fragments. The flame is 3 mm thick and separated with other bases by ceramic insulators. The cable will be connected to upper electrodes through connector made of ceramics.

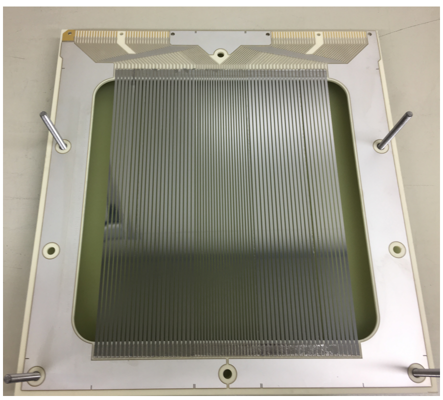

Figure 4: Horizontal target base after YAG laser cut.

For each H and V bases, ribbon width measurements were performed. The results are shown in Table 3. The ribbon width was generally smaller than the design value, and in nearly same values, blank width was larger than the design value. It indicates that the foil was over-cut by laser which had the width.

Table 3: Blank and Ribbon Width

Region	Mean (mm)	Std. deviation (%)
Horizontal Blank	1.014	2.27
Core	1.486	0.94
Halo	2.488	0.52
Vertical Blank	1.025	2.73
Core	1.473	1.09
Halo	2.479	0.61

BEAM TEST

Installation of the MRPM to the Abort line was successfully completed in the end of March 2019. The first beam study was performed in the beginning of April 2019. In the measurement, the beam energy was 30 GeV, number of bunches was 8, beam intensity was 5.4 × 10^{13} ppp with the SX beam optics. Figure 5 shows the measured results of (a) horizontal and longitudinal, (b) vertical and longitudinal beam profiles for the eight bunches.Attenuator of -20 dB was inserted to half 32 / 16 core channels and another channels' signals are multiplied to 1/10. In these measurements, first 100 samples are averaged and differentiated to remove backgrounds. The measured beam width seems smaller than expected. In particular,the left half beam of the horizontal direction was scraped. Beam loss was observed at the extraction section in this shot. It indicates that the setting of FX kickers and septum magnets was not optimized well so that a part of beam hit the beam duct and was lost. The detailed beam study of the MRPM is planned in the fall of 2019.

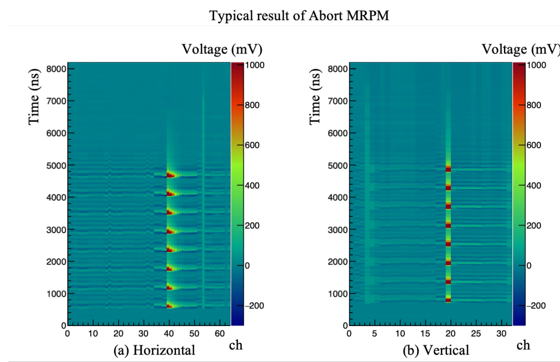

Figure 5: Abort MRPM typical profiling results.

CONCLUSION

Abort MRPM, the new beam profile monitor was installed in the abort line in MR. The real-time DAQ for three-dimensional measurement was performed successfully. The beam study for emittance and dispersion measurements of high intensity beam is planned in the fall of 2019. It is expected that the measurements will give deeper understandings in high power beam dynamics in MR for the future upgrade.

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