BEAM COMMISSIONING OF TWO HORIZONTAL PULSE STEERING MAGNETS FOR CHANGING INJECTION PAINTING AREA FROM MLF TO MR IN THE 3-GeV RCS OF J-PARC

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Abstract

We have successfully commissioned two horizontal pulse steering (PSTR) magnets installed in the Linac to 3-GeV Rapid Cycling Synchrotron injection beam transport line of the Japan Proton Accelerator Research Complex. RCS operates at 25 Hz and delivers 3-GeV beam simultaneously to the MLF (Material and Life Science Facility) and MR (Main Ring). The PSTR magnets are designed for switching injected beam trajectory in the stripper foil in order to realize a smaller transverse injection painting area as required by the MR. They have been tested for switching to a painting area of 100π mm mrad for MR from that of MLF 150π mm mrad and also used for one cycle trial operation. Their parameters were also found to be very consistent to those with designed parameters.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) is designed for a beam power of 1 MW [1]. RCS operates at 25 Hz and simultaneously delivers 3-GeV beam to the downstream muon and neutron production targets in the Material and Life Science Facility (MLF) as well to the Main Ring (MR). At present the injected beam energy is 181 MeV and the beam power for user operation has already been exceeded 300 kW [2]. The injected beam energy will be upgraded to 400 MeV later this year, while 1 MW beam power is expected to achieve in 2015.

Not only the beam power but RCS has to meet specific requirement of each downstream facility in simultaneous operation. One such issue is to maintain two different transverse sizes of the extracted beam for MLF and MR. Namely, a wider beam for MLF in order to reduce damage on the neutron production target but reversely a narrower one for the MR in order to ensure a permissible beam loss in the beam transport line of 3-GeV to MR (3-50BT) and also in the MR. In order to meet such requirements in simultaneous beam delivery, they idea here is to control transverse phase space painting area in the RCS during injection process. In addition to two existing septum magnets (ISEP1 and ISEP2) used for fixing injected beam trajectory for MLF beam, two additional dipoles named Pulse Steering (PSTR) magnets are designed for switching to a smaller horizontal angle of the injected beam at the injection point (stripper foil), so as to realize a smaller transverse painting area for the MR beam. As stripper foil position is fixed, then for MR the only choice is to control angle of the injected beam itself by using PSTR1,2. The design painting emittances for the MLF and MR are 216 and 144π mm mrad, respectively and because of the adiabatic damping the emittances finally at 3-GeV reduces to less than a quarter. The PSTRs are already installed in the Linac to 3-GeV beam transport (L3BT) line as shown in Fig. 1. The 1st one (PSTR1) locates in the upstream ISEP1, while the 2nd one (PSTR2) locates in between ISEP1 and ISEP2.

DESIGN SPECIFICATIONS

The horizontal PSTR magnets are designed for two purposes in the 400 MeV injection. First, for switching to a smaller painting area for the MR beam as already been discussed earlier. For that purpose each magnet has individual AC and bipolar power supplies [3]. Secondly, they will also be used for no painting, so-called center injection normally done in beam studies and basic parameter optimization. For that purpose there are two additional DC power supplies. This is because power supply of ISEP2 at 400 MeV injection exceeds the capacity to produce such an injected orbit in order to merge with circulating orbit bump offset produced by the chicane magnets (SB1$\sim$4) only.

Figure 2 shows a schematic view of the transverse injection painting in horizontal direction. It is performed by sweeping the closed orbit with four horizontal painting bump magnets, PBH1$\sim$4 (For vertical direction, injected beam itself is directly sweeped by two vertical kickers placed in the L-3BT line). The black and red ellipses represent painting emittances for MLF and MR, respectively. The phase space coordinates of the injected beam (blue) determines the painting emittance. Injected beam centroid at the stripper foil for MLF is fixed by ISEP1,2 for a painting area of 216π mm mrad. In this case, SBs produce a orbit bump offset of 93 mm, where phase space coordinate offset produced by PBHs are 44.9 mm and -6.5 mrad. The x and x' of the injected beam are thus 137.9 mm and -6.5 mrad, where the foil is placed. Then for switching a painting area of 144π mm mrad for MR, the most efficient way is to lower the injected beam angle to -4.4 mrad. The orbit bump offset has to then around 20% higher and becomes 113 mm.

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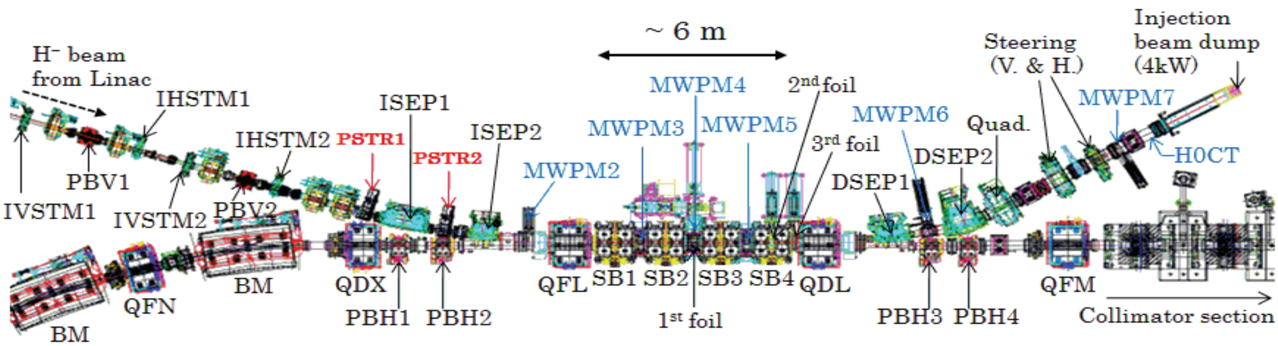

Figure 1: Layout of the RCS injection area. The PSTR magnets are installed in the injection beam transport line as shown by red arrows. Four chicane bump magnets are named as SB1∼4, while four horizontal painting bump magnets and two vertical painting bump magnets are named as PBH1∼4 and PBV1∼2, respectively.

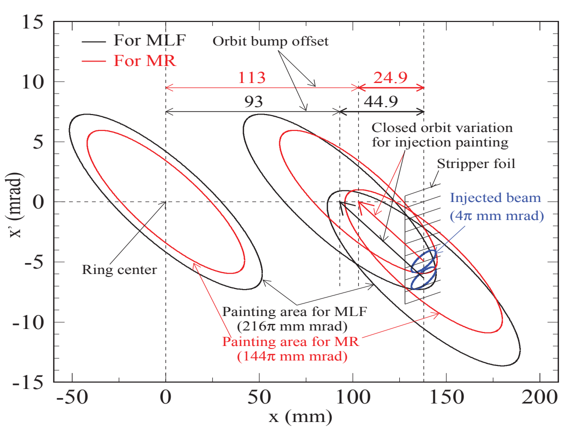

Figure 2: Schematic view of the RCS transverse injection painting in the horizontal plane. A switching of the painting area between MLF and MR is also demonstrated.

EXPERIMENTAL RESULTS

The experimental study at present was done for switching a painting area of 100π mm mrad for MR from the 150π mm mrad of MLF. Figure 3 (top) shows calculated (lines) and measured (symbols) injected beam orbits for two cases. Only ISEP1,2 are used for the MLF, while in addition PSTR1,2 are used for the MR in order to switch for the desired smaller angle of the injected beam by keeping beam position same as MLF at the foil. The solid and open circles are the measured beam positions at 4 locations and were consistent with calculated design orbits. The difference of the two orbits is shown in the inset. The maximum is about 5 mm at the QFL. The magnetic fields of PSTR1 and PSTR2 were 9.8$\times10^{-3}$ T and -4.2$\times10^{-3}$ T, respectively. The ISEP1 and ISEP2 were with 0.255 T and 0.303 T, respectively.

The no painting or the center injection has also been studied as shown in bottom of Fig. 3. The black line is the current orbit at 181 MeV, where the red line represents an equivalent center injected orbit for 400 MeV calculated by using all 4 magnets (ISEP1,2 and PSTR1,2). The ISEP2 was fixed for a certain magnetic field for which it will have a maximum field at 400 MeV. The black and red symbols

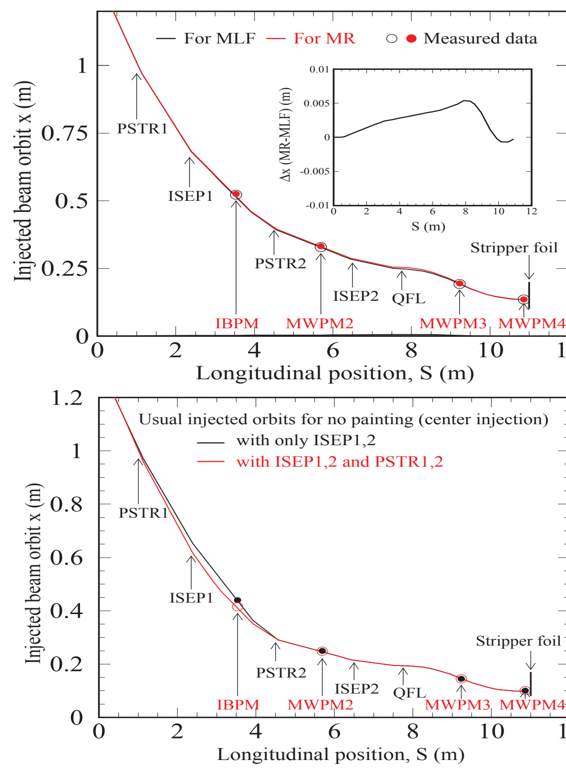

Figure 3: Comparison of the expected and measured injected beam orbits for switching painting area (MLF 150π mm mrad to MR 100π mm mrad) (upper) and also for the center injection (lower) by using PSTR magnets. A difference of two painting orbits is also shown in the inset (top). The measurements were found to be consistent with calculated design orbits.

are the corresponding measured data. The beam positions as well as parameters of all magnets used in the simulation were very consistent to those used in the experiment.

Although PSTR magnets are designed for operation in the 400 MeV injection, their performances have been checked in advanced in a trial operation at present with 181 MeV for MR painting area of 100π mm mrad changing from that of MLF 150π mm mrad. Figure. 4 (top) shows

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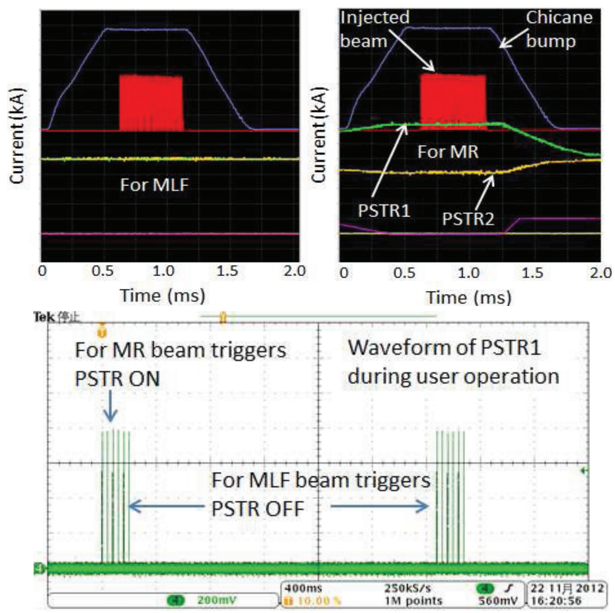

Figure 4: Waveform of the PSTR magnets while in operation and were found to be working as designed.

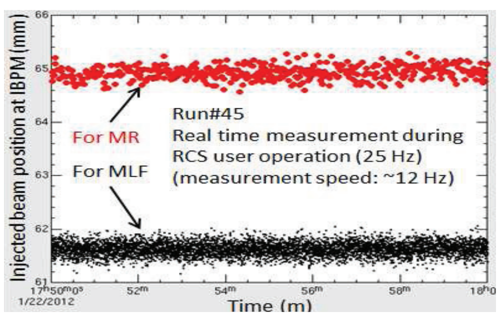

Figure 5: Injected beam positions (horizontal) measured online at the IBPM (see Fig. 3) for MLF (PSTR off) and MR (PSTR on) beam and was consistent with expectation.

snapshots of PSTRs waveforms with chicane bump coincided with injected beam (red) for both MLF and MR while in operation. The chicane bump height for MR in this condition was about 10% higher compared to that of MLF as because of the principle demonstrated in Fig. 2. A further separate snapshot of only PSTR1 waveform for a longer time range is also shown in the lower figure. In every 2.48 s, PSTRs were on for 6 MR beam triggers, while no signal for the MLF beam triggers.

Figure 5 shows online measurement of the injected beam positions (horizontal) at IBPM (see Fig. 3) while PSTRs were in operation. As expected, injected beam orbit for the MR case was shifted about 3 mm outward as compared to that of MLF.

Extracted beam profiles were also measured for transverse injection painting areas (horizontal only) of 150 (MLF) and 100 (MR)π mm mrads with an equivalent beam power of 350 kW. The measurement was done by an MWPM (Multi-wire Profile Monitor) placed in the RCS to the neutron target beam transport (3-NBT) line. Figure 6 shows measured horizontal beam profiles (red points) together with simulated profiles (lines) done by ORBIT simulation code [4]. As expected, measured as well as simulated rms width of the MR beam was confirmed to be comparatively narrower as compared to that of MLF beam.

The present result thus shows a direct evidence that by controlling initial phase space painting, the extracted beam profiles can be controlled as requested by the users even in simultaneous operation. The difference of the two profiles would be much more significant when a switching of 216 to 144π mm mrad is performed as designed (see Fig. 2) and hopefully would be done in near future at 400 MeV injection and with 1 MW.

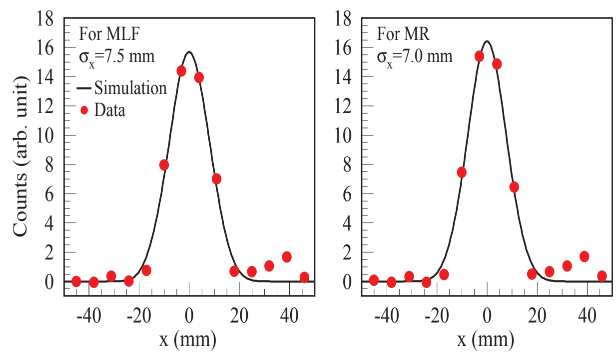

Figure 6: Extracted beam profiles with an initial smaller painting area for MR was measured to be narrower as compared to a larger painting area for MLF. The simulated profiles are also found to be consistent with measurement.

SUMMARY

Two horizontal pulse steering magnets installed in the injection beam line are found to be working as designed for switching transverse painting area pulse to pulse. It this thus confirmed that in a multi user machine beam parameters can be controlled and deliver as requested by the users even in simultaneous operation. This could be a first example of realizing such a principle in recent high intensity accelerators to meet users request in advanced ways.

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