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FOIL HITS REDUCTION BY MINIMIZING INJECTION BEAM SIZE AT THE FOIL IN J-PARC RCS

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Abstract

The uncontrolled beam loss caused by the foil scattering of the circulating beam during multi-turn charge-exchange injection is one of the main sources for high residual radiation at the injection area of J-PARC (Japan Proton Accelerator Research Complex) 3-GeV RCS (Rapid Cycling Synchrotron). It is thus one concerning issue for beam intensity ramp up and operation at the designed 1 MW beam power. We studied to reduce circulating beam hits on the foil by minimizing the vertical injection beam size at the foil and using a smaller size of vertical foil. The vertical injection beam size was reduced to 1.2 mm (σ) from its original 1.8 mm, so as to reduce the vertical foil size from 20 mm to 14 mm. As a result, the number of circulating beam passing through foil was significantly reduced due to smaller foil size. A 30% foil hit reduction, as expected in the numerical simulation was achieved in the measurement.

INTRODUCTION

The 3-GeV RCS (Rapid Cycling Synchrotron) at J-PARC (Japan Proton Accelerator Research Complex) delivers high intensity proton beam to both MLF (Materials and Life Science Experimental Facility) and the MR (30-GeV Main Ring Synchrotron) [1]. The injection beam energy is 400 MeV, which is accelerated to 3 GeV at repetition rate of 25 Hz and simultaneously delivered to the MLF and MR. The designed beam power is 1 MW (8.33×10^{13} protons/pulse), while it is 700 kW and nearly 800 kW equivalent beam power to the MLF and MR, respectively.

To increase circulating beam intensity, multi-turn charge-exchange injection of negative hydrogen (H^-) has been implemented in the RCS [1]. Figure 1 shows a layout of the RCS injection area. A thin stripper foil called HBC (Hybrid type Boron-doped Carbon) [2] (named 1st foil in Fig. 1), thickness of 333 $\mu g/cm^2$ is used for stripping 99.7% of H^- to proton (p) for injecting into the ring. The remaining 0.3% of the H^- are mainly the single electron stripped called neutral hydrogen H^0, where the un-stripped H^- are ideally negligibly small. The H^0 and any un-stripped H^- are further stripped to p by the secondary foils and directed to the injection beam dump (I-Dump) [3].

To reduce foil scattering beam losses caused by the circulating beam hitting the foil during multi-turn injection, transverse painting (TP) at injection has also been adopted to reduce circulating beam hitting rate on the foil [4, 5]. A schematic view of transverse injection process has also been

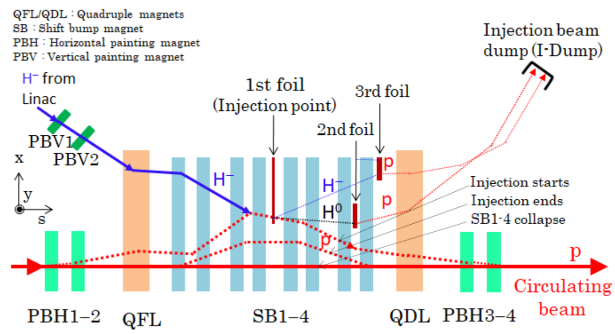

Figure 1: Layout of the RCS injection area and a schematic view of the TP process at injection. The PBHs and PBVs are horizontal and vertical painting magnets, respectively.

demonstrated in Fig. 1. The transverse painting in the horizontal plane is performed by sweeping circulating beam away from the from the foil by using four horizontal painting bump magnets (PBH), where vertical injection beam angle during injection is varied by using two vertical painting bump magnets (PBV) placed at injection beam transport (BT). The average foil hits of the circulating beam for the MLF is lowered to around 7 by applying a painting area of 200π mm mrad. However, the residual radiation at the injection area caused by the foil scattering beam losses is very high even at a lower beam power [6]. It is already an issue for regular maintenance work at the injection area and thus one big concern for beam power ramp up and maintain a stable operation at the designed 1 MW beam power. It is thus highly essential to reduce the foil scattering beam losses by minimizing the foil hits of the circulating beam.

PRESENT APPROACH

In order to further reducing circulating beam hits on the foil, a straightforward way is to minimize the foil size itself. However, this would cause an increase of missing H^- to increase the un-stripped H^- waste beam at the I-Dump. To overcome this issue, our idea is to minimize injection beam (Ibeam) size at the foil, especially the vertical size to utilize a smaller size of vertical foil as demonstrated in Fig. 2. This would allow us to reduce both sides of the vertical foil instead of a single side if doing for the horizontal size as the foil is installed horizontally. It is worth mentioning simultaneous manipulation of the Ibeam for both horizontal and vertical planes or even an extreme manipulation in a single plane by keeping other plane unchanged is difficult due to already existing magnet configuration and the aperture of the BT. We considered nearly a half reduction of the vertical

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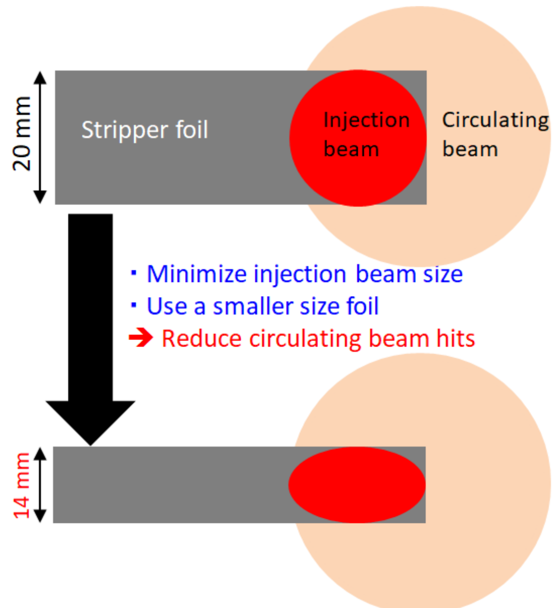

Figure 2: A schematic view of the present idea to reduce foil hits of the circulating beam by minimizing vertical Ibeam size at the foil and using a smaller size vertical foil.

Ibeam size to reduce the vertical foil size from its 20 mm to 14 mm. The Ibeam size is minimized by manipulating the twiss parameter, namely its vertical beta function (β_y) at the foil. We estimated that the β_y at the foil can be reduced to 3 m from the original value of 8 m by keeping other parameters unchanged and without any aberration of the beam envelope at the BT.

Figure 3 shows an expected foil hit reduction estimated from the numerical simulation for 1 MW beam power and applying a large painting area of 200π mm mrad for both horizontal and vertical planes. The horizontal axis is the turn number, where vertical axis average is the foil hits of each circulating proton injected into the ring. We have estimated that the average foil hits can be reduced to 27% by reducing injection β_y to 3 m and using a smaller vertical foil size of 14 mm (red) as compared to that for a β_y of 8 m and using a vertical foil size of 20 mm (black).

MINIMIZATION OF THE IBEAM SIZE

As mentioned in the previous section, the Ibeam size was minimized by manipulating its vertical beta function β_y at the foil. Five quadruples at the downstream of the injection BT was used for that purpose. Table 1 listed measured major twiss parameters of the Ibeam optimized for this study as well as the original ones. As expected, the β_y at the foil was reduced to 3 m from its original 8 m without almost any change of other parameters. Figure 4 shows a comparison of the measured vertical profiles of the Ibeam at the foil for β_y 3 m and 8 m depicted by the red and black lines, respectively. A profile width of 1.8 mm (σ) could be reduced to 1.2 mm, with a reduction of nearly 35%.

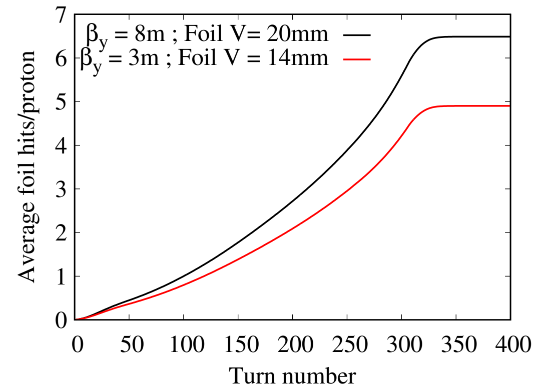

Figure 3: Estimation foil hit reduction as obtained from numerical simulation. A 27% reduction is expected by minimizing the Ibeam size and using a smaller size foil.

Table 1: Measured twiss parameters of the Ibeam at the foil. The β_y is reduced from 8 m to 3 m to minimize the Ibeam size. The given emittances are un-normalized ones.

Parameter	Original	This study
α_x	-0.5035	-0.3210
α_y	-1.5686	-0.3996
β_x [m]	6.1927	6.2907
β_y [m]	8.1744	**3.0588**
ϵ_x (σ) [π mm mrad]	0.5148	0.5740
ϵ_y (σ) [π mm mrad]	0.4010	0.4338

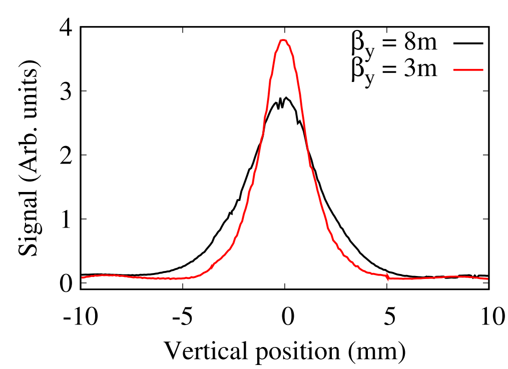

Figure 4: Measured vertical Ibeam profiles at the foil. The profile width by manipulating β_y was reduced to 1.2 mm (σ) from its original 1.8 mm.

MEASUREMENT OF FOIL HIT REDUCTION

We have also measured foil hits of the circulating beam for both β_y of 8 m and 3 m for 1 MW beam power by applying a large painting area of 200π mm mrad. The measurement was done by using a plastic scintillator counter named beam loss monitor (BLM) placed 90^o above the foil in the horizontal direction. Secondary particles such as, γ rays were measured, which were generated due to large angle foil scattered particles lost nearby. The position of the BLM was thus to choose to avoid any primary proton hitting. Figure 5

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shows picture of the foils used for the measurement. A vertical size of 20 mm (top) was used for injection β_y of 8 m, while it was 14 mm (bottom) for that of 3 m.

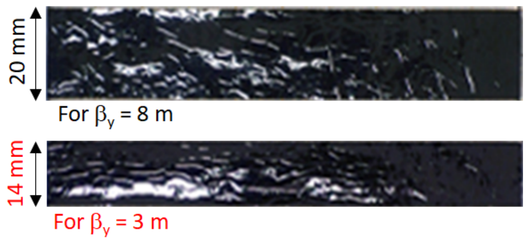

Figure 5: Photographs of the foils with two different vertical sizes of 20 mm (top) and 14 mm (bottom) used for measuring the foil hits for β_y of 8 m and 3 m, respectively.

Figure 6 shows measured BLM signals as a function of time for β_y of 8 m (black) and 3 m (red) with corresponding vertical foil size of 20 mm and 14 mm, respectively. A reduction of the RAW signal for the later case thus reflects a reduction of the foil hits.

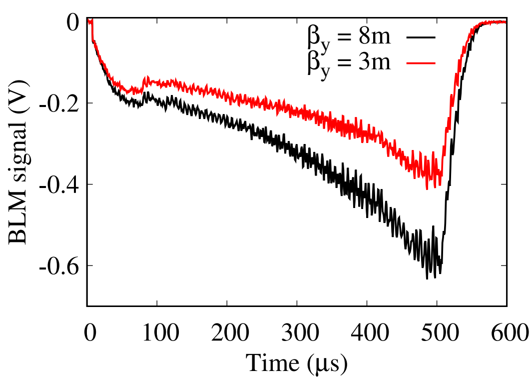

Figure 6: Measured signals of the BLM for β_y of 8 m (black) and 3 m (red).

Figure 7 shows absolute values of BLM integrated signal, where high voltage (HV) of the photo multiplier tube (PMT) was changed. The integrated signal of the BLM for the varied range of HV was found to linear at least at higher HVs for both β_y. A reduction of the foil hits was calculated by taking a ratio of the integrated signal taken at the highest HV for a smaller β_y of 3 m to that with the original β_y of 8 m. The result is shown in Fig. 8, where BLM integrated signal for β_y of 8 m with HV of 2 kV is normalized to unity to obtain the reduction rate for a minimized β_y of 3 m. We obtained a foil hit reduction of 31% (red), which is almost consistent to our expected value of 27% (black).

It is worth mentioning that we have confirmed the total beam loss in the RCS from beam injection until extraction remains almost same by using a smaller injection β_y as compared to that with original β_y. It has also been confirmed that there was no additional missing and un-stripped H^- even using a smaller size foil for a smaller β_y of 3 m. A smaller injection β_y and a smaller vertical size foil of 14 mm have also been implemented for the RCS operation recently.

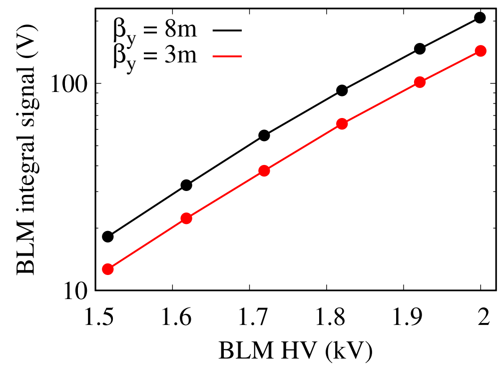

Figure 7: Measured absolute values of the integrated signal of the BLM taken by changing the HV of its PMT. The BLM signal for a smaller β_y reduces for any HV applied.

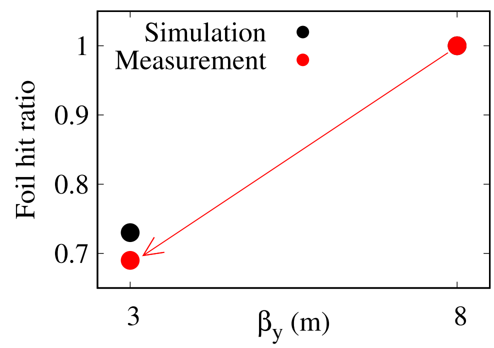

Figure 8: Measurement result of foil hit reduction for β_y of 3 m as compared to the normalized foil hits to unity for β_y of 8 m. We obtained a reduction of 31%, which is almost consistent to the expected one of 27% as shown in black.

SUMMARY

High residual radiation at the injection area caused by the foil scattering beam losses of the circulating beam is one of the concerning issue at high-intensity operation. To reduce residual radiation at the injection area caused large angle foil scattering of the circulating beam, we have studied to minimize vertical injection beam (Ibeam) size by manipulating its β_y at the foil essentially to use a smaller size vertical foil. The β_y was optimized to 3 m from its original value of 8 m and the corresponding vertical Ibeam size (σ) was thus reduced to 1.2 mm from 1.8 mm, which allowed us to reduce the vertical foil size to 14 mm from the original one of 20 mm. As a result, we obtained a foil hit reduction of 31% measuring large angle foil scattering beam losses by using BLM placed 90^o above the foil in the horizontal direction. The measurement result was consistent to an expected reduction of 27% obtained in the numerical simulation. Such a smaller β_y and a vertical foil size of 14 mm have also been implemented for the RCS operation recently, which would play an important role to reduce uncontrolled foil scattering beam losses and the corresponding high residual radiation at the injection area for the present as well as near future operation at 1 MW beam power.

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