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THE MITIGATION SYSTEM OF THE LARGE ANGLE FOIL SCATTERING BEAM LOSS CAUSED BY THE MULTI-TURN CHARGE-EXCHANGE INJECTION*

S. Kato[#1], K.Yamamoto[2], H. Harada[2], H. Hotchi[2] and M. Kinsho[2]
[1]Tohoku University, Sendai, Miyagi, Japan
[2]J-PARC/JAEA, Tokai, Ibaraki, Japan

Abstract

In the J-PARC 3GeV rapid cycling synchrotron (RCS), the beam losses caused by the large-angle scattering of the both injected and circulating beams at the charge-exchange foil were observed downstream of the injection point. To realize high power operation, these losses had to be mitigated or localized in terms of exposure to radiation. Therefore, a new collimation system was developed and installed in the 2011 summer shutdown. In the beam commissioning at 181 MeV injection energy, these uncontrolled beam losses were successfully localized. Since the injection energy has been upgraded to 400 MeV in 2013 summer-autumn maintenance period, the readjustment of the collimator was performed. In this paper, the collimation system is introduced and the adjustment results are reported.

INTRODUCTION

In order to achieve a high intensity, the RCS has the multi-turn charge-exchange injection scheme using H^- beams [1]. The schematic drawing of the RCS injection scheme is shown in Fig. 1. During the 500 µs injection period, four shift-bump magnets (SB1-4) shape the fixed orbit bump and four paint-bump magnets (PB1-4) shape the time-decay orbit bump. The H^- beams from the Linac are transported to the injection point and almost converted into H^+ by the 1st charge-exchange foil and injected into the ring, which is divided into several hundred turns. During injection, the injection orbit is fixed and the ring orbit is shifted slightly from the foil by decreasing the time-decay orbit bump height for the painting injection.

Though this injection scheme is a powerful technique in order to form a high intensity beam, the both injection and circulating beams hit the foil and their beams are scattered

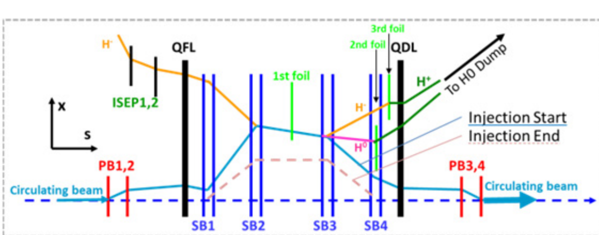

Figure 1: The schematic drawing of the RCS injection scheme.

*Work supported by the JSPS Research Fellowships for Young Scientists
#skato@post.j-parc.jp

repeatedly during injection. Therefore, the large-angle scattering beam loss becomes serious issue though the probability of the large-scattering events is very low [2]. These are caused by the multiple Coulomb scattering.

The simulation result of tracks of particles which given large angle is shown in Fig. 2. Some local loss points arise in the horizontal plane. Actually, the measured residual doses were 4.5 mSv/hr at the H0 branch duct and 6.2 mSv/hr at the inside of the Beam Position Monitor (BPM) which was put downstream of the H0 branch duct after 220 kW routine operation at 181 MeV injection.

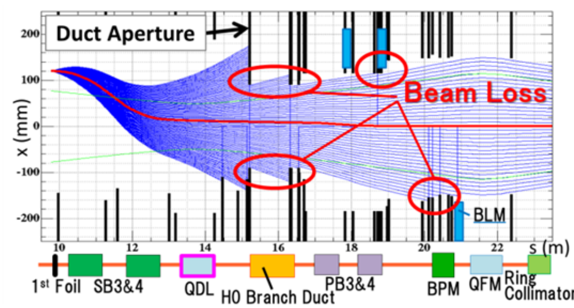

Figure 2: The horizontal particles tracking simulation result. Blue lines are tracks of particles which gave arbitrary angles at injection point. Blue boxes indicate the location of the Beam Loss Monitor.

Therefore, a new H0 branch duct which includes inside and outside absorbers was installed as a new collimation system in order to localize the loss between the H0 branch duct and the Ring Collimator [3] to realize a high-intensity. When the injection energy was 181 MeV, these uncontrolled beam loss was successfully localized [4] [5]. In 2013 summer-autumn maintenance period, the injection energy was upgraded to 400 MeV. Therefore, the performance of the collimator was examined.

H0 COLLIMATION SYSTEM

Absorber Design

Two absorbers are main components of the collimation system. The schematic drawing of the absorbers is shown in Fig. 3. The material is oxygen-free copper. These absorbers were designed to have angles in order to made scattered particles to collide with the front of that and to keep a sufficient fright distance in the absorber. In addition, each absorber position and angle can be adjusted by the expansion, contraction and rotation of the support rods along the change of the operation parameters.

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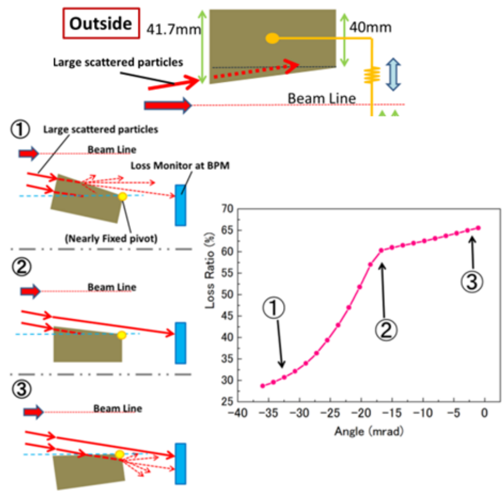

Figure 4: The outline of the beam based regulation method. The left figures show schematic drawing of the absorber rotation. The right figure shows the simulation result of the loss dependence on the surface angle of the absorber.

Simulation Set

The characteristic point of this system is that the realistic simulation is also constructed in order to comprehend absorber states well and estimate the amount of loss for the high intensity operation. In this simulation set, some effective simplification is adopted in order to calculate the large-angle scattering beam losses which are rare events in several days as follows. First, the distributions at the foil are obtained using a multi-particles simulation. Second, the scattering angle which is large enough to cause the beam loss is added to these particles. Finally, particles are tracked to Ring Collimator.

In the past simulation, the space charge effects and the effect of the transverse emittance growth by the foil hit were neglected. Therefore, SIMPSONS which is the multi-particles simulation code including the space charge effects [6] is adopted as a multi-particles simulation in order to consider those effects in this time.

When the dependence on the surface angle of the absorber is examined, the GEANT4 simulation is replaced at the absorber section in order to consider the interaction between particles and materials..

Beam Based Angler Regulation Method

In order to align the large-angle scattered particles and the surface of the absorbers in parallel, the beam based angler regulation method was adopted using the Beam Loss Monitor (BLM). BLM was plastic scintillator type and the time structure of the loss can be observed. The brief explanation of the method is as follows.

First, the scattering beam loss where the arbitrary BLM is arranged is left by adjusting the insertion distance as the case 2 in Fig. 4. Next, the absorber is rotated. Therefore, the two cases occur. One is that the tip of the absorber cut off the loss particles as the case 1 in Fig. 4. Another is that the loss increases because the fright distance in the absorber decreases as the case 3 in Fig. 4. Accordingly, the typical loss dependence on the surface angle can be obtained as the right figure in Fig. 4 and the turning point can be identified as the target angle. This unique method called Loss Monitor Method (LMM) was established in injection energy of 181 MeV.

THE RESULTS OF THE REGULATION TEST

The results of the regulation test are explained in the following section. In the RCS, the insertion distance which is required to remove downstream loss is different between the injection start and the end because the paint-bump magnets change their current during the injection. In addition, in 400 MeV injection, the shift-bump magnets also change owing to the restriction of the power supply differently from the case of 181 MeV injection. The outside absorber is required long insertion distance in the injection start. On the other hand, the inside absorber is required that in the injection end. Therefore, the beam was injected during first 100 μs in the injection period when the outside absorber position was adjusted. On the other hand, the beam was injected during last 100 μs when the inside absorber position was adjusted.

In contrast with the insertion distance, the scattered particle angle at the absorber hardly changes during the injection period as long as the current of the shift-bump magnets is constant. However, the angle also changed as mentioned above in this time. Therefore, the angle optimizations of the outside and inside absorber were performed during first and last 100 μs in the injection period in the same way as the adjustments of the position, respectively.

Position Optimization

The loss dependence on the inside absorber insertion at the inside of the BPM is shown in Fig. 5. The simulation result is also shown in same plot. The BLM location is shown in Fig. 2. The loss was removed when the absorber position was over -55 mm. In this simulation, the inserted apertures which are substitutes for the absorbers remove the colliding particles absolutely. Therefore, the zero value of the simulation results was considered as the average value of experimental data over -50 mm in Fig. 5. As a result, this experimental result is good agreement with the simulation one.

When the absorber is inserted too far, it can shave the circulating beam undesirably after injection period. The loss dependence after 700 μs at the outside of the PB3 is shown in Fig. 6. The beam loss which doesn't exist primarily occurs when the position was over -56 mm. From these results, the position was determined as -58 mm though the loss was not removed completely. The cause of the residual loss was that the larger insertion distance was required than designed one owing to the time decay of fixed orbit bump as mentioned above.

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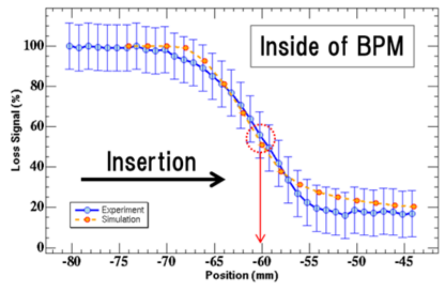

Figure 5: The loss dependence on the position of the inside absorber at the inside of the BPM. Blue points are the experimental data. Orange points are the simulation data.

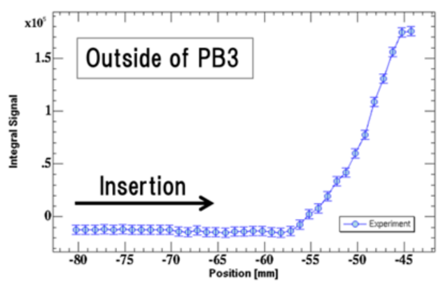

Figure 6: The loss dependence on the position of the inside absorber at the outside of the PB3.

Angle Optimization

From the results of Fig. 5, the LMM was performed at the inside of the BPM with the -60.23 mm inside absorber position. The loss dependence on the surface angle is shown in Fig. 7. The typical loss dependence was obtained as expected. From this result, the angle was determined -18.77 mrad. In this figure, the horizontal axis of the simulation result was corrected to be same the experimental result. The loss value of the simulation

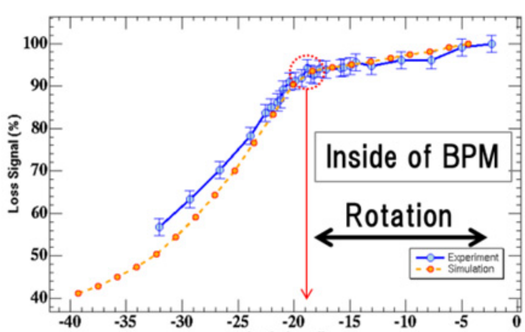

Figure 7: The loss dependence on the surface angle of the inside absorber at the inside of the BPM. Blue points are the experimental data. Orange points are the simulation data.

result was normalized by using only the value of the turning point. As a result, this experimental result is good agreement with the simulation one. In other words, the horizontal axis of the experimental result was shifted approximately 1.27 mrad from the simulation result. The cause was alignment error and ring COD. From these results, it can be pronounced that the beam based regulation method is effective to achieve efficient localization.

User Operation Result

The beam losses at the inside of the BPM with and without absorbers are shown in Fig. 8. The beam intensity corresponded to 300 kW. Although the loss around the end of the injection period remained owing to the time decay of the shift-bump magnets current, the beam loss was localized sufficiently. The outside absorber was also regulated using the BLM at outside of the PB4.

Finally, the scattering beam loss occurring at the inside of the BPM and the outside of the PB4 were decreased to 25.4% and 21.3%, respectively. The residual doses were 0.90 mSv/hr and 0.26 mSv/hr after one operation cycle at a 300 kW, respectively. After all, the maintenance of the devices around the BPM and the more high-intensity beam operation became possible. In addition, the loss at the inside of the BPM will be more suppressed when the power supply of the shift-bump magnet will be upgraded in this summer shutdown.

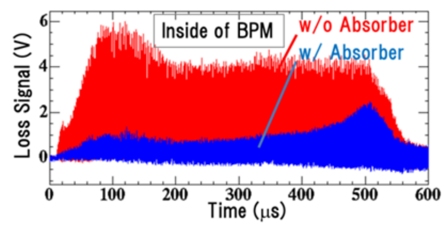

Figure 8: BLM signal at the inside of the BPM with or without absorbers insertion.

SUMMARY

In the RCS, a new collimation system was adopted in order to localize the large-angle scattering beam loss. Through the simulation and the beam commissioning, the regulation method of the collimator was established and these losses could be localized sufficiently. This localization method will be able to serve as a general method in some high-intensity accelerators.

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