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

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Abstract

In the J-PARC 3GeV rapid cycling synchrotron (RCS), the significant losses were observed at the branch of H0 dump line and the Beam Position Monitor (BPM) which was put at the downstream of the H0 dump branch duct. These losses were caused by the large angle scattering of the injection and circulating beams at the charge-exchange foil. To realize high power operation, we had to mitigate these losses. So, we started to develop the H0 branch duct as a new collimation system and installed in October 2011. In order to optimize this system efficiently, we simulated and researched most optimized position and angle of the absorber. In this process, we devised the method of angle regulation of the absorber. We present the outline of this system, the method of angler regulation of the absorber, and performance of this new collimation system.

INTRODUCTION

The RCS adopts the multi-turn charge-exchange injection scheme using H^- beams. The H^- beams with a kinetic energy of 181 MeV from the Linac are transported to injection point and almost stripped to H^+ by charge-exchange foil and injected into the ring divided 235 turns. The unstripped beams (H^0 and H^-) are converted to H^+ by 2nd and 3rd foils at downstream of injection point and led to H0 dump. The layout of the injection area is shown in Fig. 1. In addition, the injection energy will be upgraded to 400 MeV in 2013 summer.

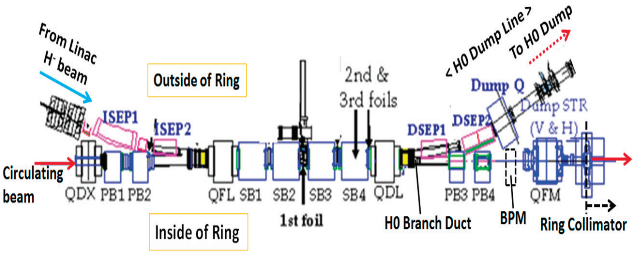

Figure 1: Layout of the injection area.

In the RCS, the significant losses were observed between H0 branch duct and QFM which is quadrupole magnet located downstream of injection after continuous user operation. In particular, the residual doses were 4.5 mSv/hr at the branch of H0 dump line and 6.2 mSv/hr at the inside of the BPM which was put at downstream of the H0 branch duct after 220 kW one cycle operation. From a point of the exposure to radiation during maintenance, we couldn't ignore these losses.

The results of some experiments and simulations indicated that, it became clear that these losses were caused by the large angle scattering of the injection and circulating beams at the charge- exchange foil during the multi-turn injection [1]. Then, to realize much higher power operation, we decided to localize these losses in the H0 branch duct by developing a new collimation system [2].

H0 COLLIMATION SYSTEM

The Structure of H0 Collimation System

The QDL which is horizontal defocus quadrupole magnet is installed at upstream of H0 branch duct. The scattered particles are subjected to the influence of QDL and a horizontal angle increases. Therefore, the sources of these losses are almost scattered particles which have large horizontal angle. The result of scattered particles tracking simulation is shown in Fig. 2.

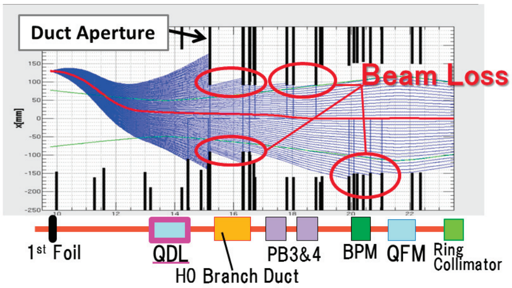

Figure 2: The horizontal scattering beam tracking simulation. Blue lines are tracks of particles which gave arbitrary angles at injection point.

The large scattered particles are lost at H0 branch and BPM at which aperture is small. As a result of tracking simulation, it became clear that the minimum horizontal scattering angle which particles might be lost was about ±3 mrad. On the other hand, the minimum vertical scattering angle which particles might be lost was about ±10 mrad. As a result of GEANT4 which is particle reaction simulation, it became clear that the probability of occurrence of such cases is about 10^{-5}.

In order to localize these losses, we decided to develop the new H0 branch duct as a new collimation system. This system consists of the curved duct connected with the H0 dump line and the linear duct connected with the ring and

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two absorbers included in most downstream of linear duct. The construction of this system is show in Fig. 3.

The absorbers remove the particles which lost between the absorbers and QFM. This system is covered with the radiation shield. This shield also covers a dump septum magnet (DSEP1). All of this system installed on linear motion guide including DSEP1, we can take it out easily when we have to replace this system.

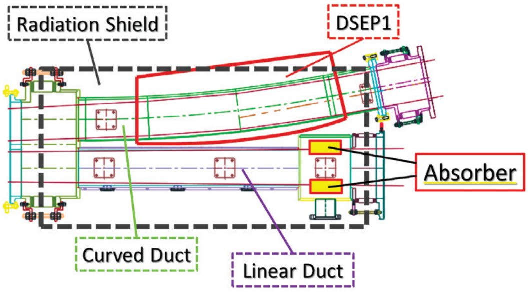

Figure 3: The construction of H0 Collimation System.

The Design of H0 Duct

In order to suppress the perturbation of the circulation beams, the H0 branch duct needs reducing the magnetic field made by DSEP1 in linear duct. However, there isn't enough space to insert sufficient shield in order to shield fringing field from DSEP1. Therefore, we have developed the linear duct using the SUS430 which has magnetic property. This duct needs not only magnetic shielding effect but also a low outgassing property. So that it can be used for a high intensity particle accelerator. Therefore, we examined magnetic shielding effect and outgassing rate of SUS430 duct [3] [4]. From these result, it was expected that the influence on circulating beams was very small.

The Design of Absorber

The absorber must meet the some requirements. First, the absorber must have a low outgassing rate. Therefore, we decided to develop this by using oxygen-free copper which has been used as Ring Collimator in the RCS. Second, the absorber must be located right and left in horizontal plane and have enough longitudinal length. Because the range of 400 MeV proton in oxygen-free copper is about 130 mm, we decided absorber length 200 mm with margin. Third, the beam side of the absorber must have angle. The schematic drawing is shown in Fig. 4.

If the absorber is rectangular parallelepiped, the scattered particles spread horizontally collide with the side of absorber. In that case, a sufficient fright distance in the absorber isn't kept and particles aren't well absorbed. Therefore, we design the absorber with angle and made scattered particles to collide with the front of the absorber. Finally, the absorber must be able to adjust its position from center of beam and angle of beam side along the change of operation parameters. Therefore, we enable to adjust absorber position by expansion and contraction of its support lot and its angle of the beam side by rotating whole focusing on the axis of rotation which is at the lowest stream of the absorber.

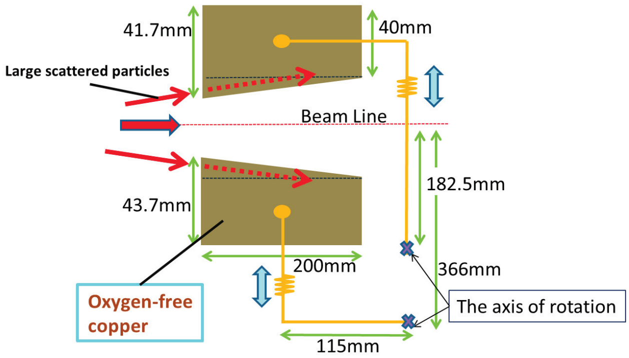

Figure 4: The schematic drawing of absorber.

THE METHOD OF REGULATION OF ANGLE OF ABSORBER

In order to estimate about the localization effect of this system, we constructed simulation model. We constructed absorber structure and adjustment mechanism in GEANT4 and combined this with SAD which is beam tracking code and performed simulation. As a result of simulation, it suggested that the angle of scattered particles and the beam side of the absorber should be same in order to localize efficiently.

Thus, we devised the method of regulation of angle of absorber. We call this Loss Monitor Method (LMM). The detail of this method is explained using Fig. 5 as follows. The inside of the ring is explained. First, we left losses at BPM intentionally by not inserting the absorber completely. Since the axis of rotation of absorber is downstream of it, the inner edge of downstream of absorber is almost fixed. The scattered particles and the beam side of the absorber are parallel in case 2. In the case of 1, the loss decrease compared with the case 2. This is because the upstream edge of absorber approach beam centre and particles collide additionally compared with the case 2. On the other hand, in the case 3, the loss increase gradually compared with the case 2. This is because particles which collide with the front of the absorber in the case 2 collide with the side of the absorber and leak in the case 3. After all, the inflection point of the transition of losses is the absorber angle which is the same as scattered particles.

We examined loss dependence on the angle of absorber between absorber and QFM. As a result, it could be confirmed that not only the sufficient fright length in the absorber could be kept for scattered particles but also the losses could be minimized by optimization using LMM.

In addition, as a matter of course, the additional insertion after optimization of the angle using LMM is required to remove losses completely.

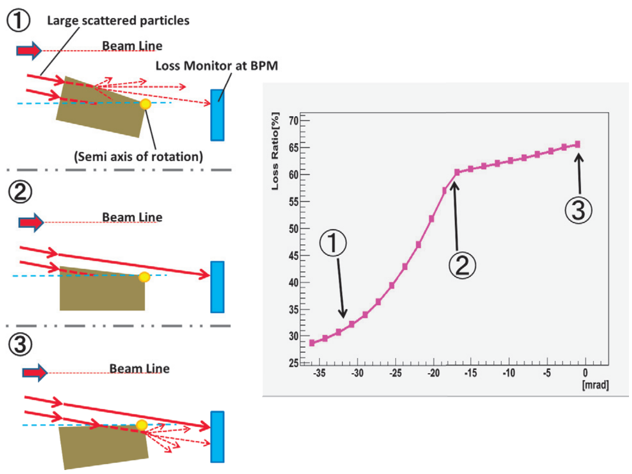

Figure 5: The detail of LMM. The left figures show schematic drawing of rotation of the absorber set at the inside of the ring. The right figure shows the transition of losses at the inside of the BPM.

THE RESULT OF BEAM TEST

The Effect by Insertion of Absorber

We examined the loss reduction between H0 Collimation System and QFM by insertion of the absorber. As a result, we were able to confirm that the loss caused by foil scattering at the inside of the BPM was suppressed by inserting of the absorber. On the other hand, the loss increased at the other side of inserted absorber when absorber was inserted too much. Because the absorber behaved as Ring Collimator and the halo particles were scattered by this absorber. From this result, we were able to understand the limit of the amount of insertion.

In the same way, the result of insertion of the absorber set at the outside of ring, we were able to confirm that the loss caused by foil scattering at the outside of the PB4 was suppressed by inserting the absorber.

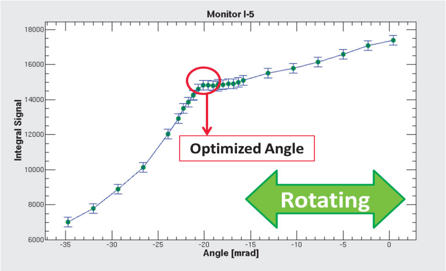

Figure 6: The loss dependence on rotating of the absorber set at inside of the ring at the inside of the BPM.

Optimization of the Absorber Angle

We examined whether LMM could be used as optimization method of absorber angle. We adjusted the amount of insertion to remain some losses located at the inside of the BPM or the outside of the PB4. We detected the transition of losses at these points rotating the absorber. The result of rotating of the absorber set at the inside of the ring is shown in Fig. 6. The transition of losses at the inside of the BPM had the inflection point. This was the same as the result of simulation. Moreover, it was confirmed that the losses at the other points were minimum when the angle of the absorber corresponded with the inflection point. After all, it was confirmed that the LMM was able to be used for optimization of the absorber. The same result was obtained about the absorber set at the outside of ring.

The Result of User Operation

We examined the effect of the H0 Collimation System using same beam parameter as 220 kW user operation. The absorber was inserted sufficiently after optimization using LMM.

The losses located at the inside of the BPM and the outside of the PB4 decreased due to insertion of the absorber and became 12% and 2% respectively compared with that when the absorber was extracted. After all, we achieved localization of losses between H0 branch and QFM. In addition, the residual dose distribution of whole RCS ring didn't change before and after insertion of the absorber.

The residual dose at the inside of the BPM was 230 μSv/hr after one cycle operation at 120 kW output beam power with H0 Collimation System. This value is about 1/10 compared with before. Moreover, the residual doses on the radiation shield of the H0 Collimation System and at the upstream of H0 branch which wasn't covered by shield were lower than 5 μSv/hr and 230 μSv/hr respectively. Those were enough low to maintain RCS.

CONCLUSION

To realize much higher power operation, we developed H0 Collimation System in order to localize the losses caused by the large angle scattering at the charge-exchange foil. We designed the H0 duct and the absorber. We constructed simulation model to examine the performance of this system. As a result, it became clear that the optimization of angle of absorber was important and LMM was able to be used as optimization method.

As a result of beam test, we confirmed that the H0 Collimation System localized the losses. Moreover, we were able to optimize angle of the absorber using LMM.

We were able to confirm that the residual doses were suppressed by H0 Collimation System and the values of these were enough to low to maintain the RCS.

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