NEW INJECTION SCHEME OF J-PARC RAPID CYCLING SYNCHROTRON

K. Yamamoto†, J. Kamiya, P. K. Saha, T. Takayanagi, M. Yoshimoto, H. Hotchi, H. Harada
Accelerator Division, J-PARC Center, Japan Atomic Energy Agency (JAEA), Tokai-mura, Japan
O. Takeda, N. Miki, Nippon Advanced Technology Co., Ltd., Tokai-mura, Japan

Abstract

The 3-GeV Rapid Cycling Synchrotron of Japan Proton Accelerator Research Complex aims to deliver 1-MW proton beam to the neutron target and Main Ring synchrotron. Present beam power of the Rapid Cycling Synchrotron is up to 500-kW and the higher radiation doses were concentrated in the injection area. These activations were caused by the interaction between the foil and the beam. To reduce the worker dose near the injection point, we have studied a new design of the injection scheme to secure enough space for radiation shielding and bellows. In the new system, two of four injection pulse bump magnets are replaced and we are able to ensure the additional space around the injection foil chamber. So far, new injection system seems not impossible. However, preliminary study result indicated that temperature of the duct and shielding metals would be slightly higher. The eddy current due to the shift bump magnet field generates heat. Thus we have to study details of above effect.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of Japan Proton Accelerator Research Complex (J-PARC) was constructed to supply 1-MW, high-power proton beam to the Main Ring synchrotron and Material and Life science Experimental Facility (MLF) [1]. In the proton accelerator, the most important issue is radio-activation caused by the beam loss. The interaction between the high energy beams and the materials of the accelerator components make various kinds of radioactive nuclides. When the beam loss increases, failure rates of the accelerator components and worker doses during maintenance work would also increase. Then, the output beam power has to be limited to keep the exposure dose for the workers by the residual dose within acceptable tolerances. In order to achieve high-power beam acceleration such as 1-MW, it is important to reduce and to counter the beam loss. We designed a beam collimation system for this purpose. This beam collimation system is arranged in order to remove the beam halo and to localize the beam loss in itself [2]. We also continue the beam study to reduce the beam loss, and now the major activated point is the only injection foil chamber. RCS beam power is at most 500-kW at present, and the residual dose value on the surface of the injection foil chamber was about 10 mSv/h at 4 hours later from beam stop. The radio-activation of the injection area will become the issue in future when we increase the output power of RCS. Therefore, we have to take measures of the radio-activation of the injection area.

* e-mail:kazami@post.j-parc.jp

RESIDUAL DOSE DISTRIBUTION AND WORKER DOSE

The residual dose distribution around the RCS is shown in Fig. 1. Here we display the representative points which values are higher than the circumference. These values were measured in April 2015. The beam power was 400-kW or 500-kW in this time.

In the RCS, higher dose values are concentrated on the collimators and near the injection point. The residual dose values are less than 1 mSv/h in other points. The maximum dose point is a flange which is located just downstream of the injection foil, and its value is 15 mSv/h after 400-kW operation. Table 1 shows a summary of the worker dose during summer shutdown period 2015. Water leak of the neutron target occurred at the end of April 2015, and the only beam operation to the MR was performed two months before the summer shutdown period of 2015. Since the RCS operation duty to the MR was less than 10 %, it seemed like a cooling time. Therefore, the radioactive nuclides with short half-lives disappeared and the residual dose on the foil chamber became about 3 mSv/h. This was due to long-lifetime nuclides, and therefore this value did not change over the maintenance period. During this summer shutdown period, 33 workers were exposed to a dose of more than 0.01 mSv, and the corrective dose to the RCS workers was 4.45 mSv. The maximum dose for one worker was 0.42 mSv and his work was recovery from a malfunction of the injection magnet. Since we removed the upper half of the magnet, which functioned as radiation shielding, for maintenance, a duct with high dose inside the magnet was revealed and exposure dose was increased.

In this way, the dose value of worker who worked near the injection point was about 0.5 mSv even though the activation was well reduced by the long cooling time. Therefore, we have to consider measures of the radio-activation of the injection region to achieve further high intensity operation.

Table 1: Summary of the Personal Dose During the Summer Shutdown Period of 2015 [3]

Exposuer dose [mSv]	Number of workers [#]
0.01-0.05	11
0.06-0.1	7
0.11-0.2	7
0.2-	8

ISBN 978-3-95450-182-3

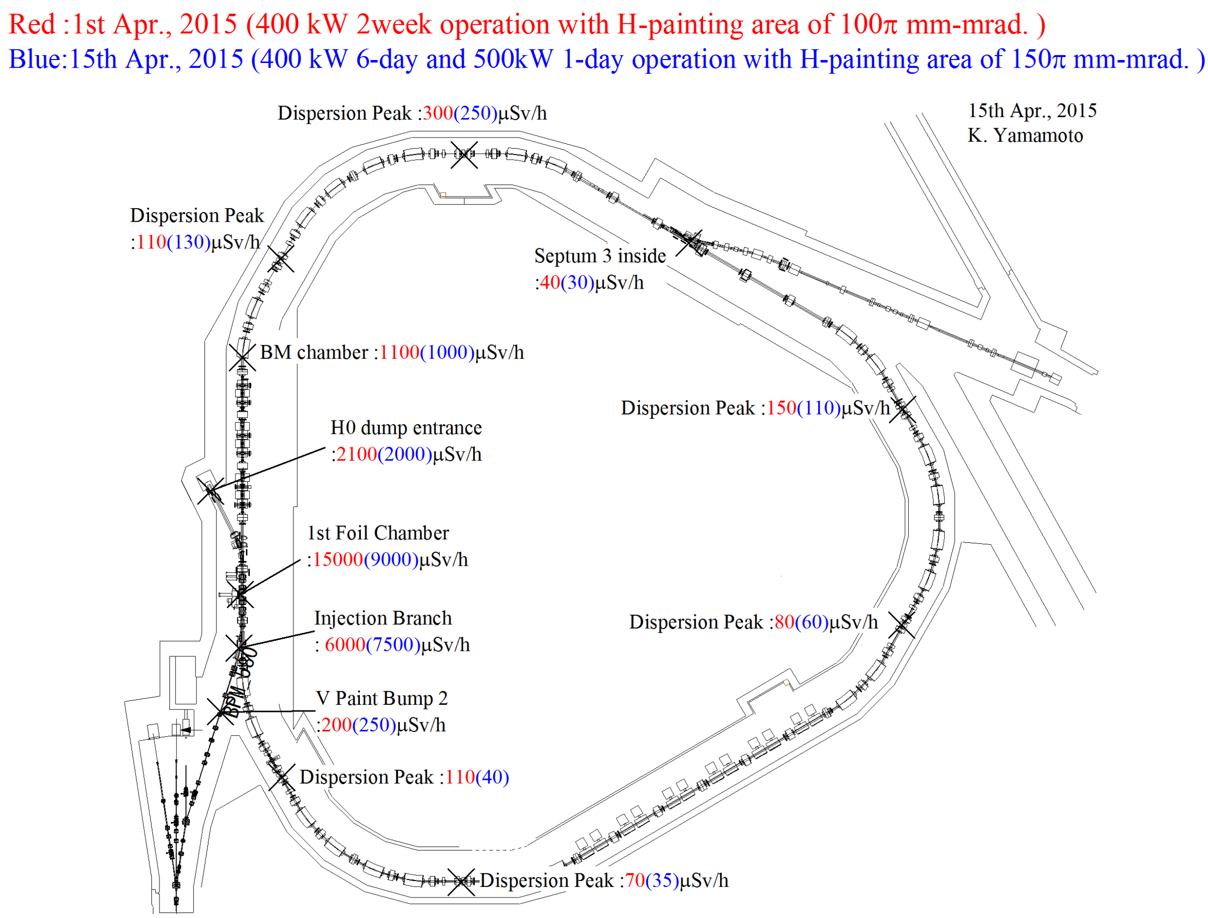

Figure 1: Residual dose distribution of the RCS before and after the 500-kW operation [3].

SOURCE OF ACTIVATION AND PRESENT COUNTERMEASURE

We investigated the source of the radio-activation of the foil chamber and found that it was due to the interaction of the injection and circulating beams with the charge-exchange foil. Figure 2 shows the loss monitor signals as a function of the average number of foil hits per particle during a beam injection under different types of operational conditions. This result indicated that the beam loss at the foil chamber is caused by the interaction of the beams with the charge-exchange foil. We also compared the measurement result of the residual dose distributions and the simulation results by the PHITS Monte Carlo code. The distribution of radioactive sources and residual dose vales obtained by the simulations are consistent with the measurement results [4]. This fact indicated that the secondary neutrons and protons derived from nuclear reactions at the charge-exchanged foil are the dominant cause to high residual dose in the injection area.

The way to decrease this activation is reduction of the interaction rate between the beams and the foil. Thus, since it was necessary to expand the painting injection area to reduce the number of the beam collision on the foil, we had to correct the modulation of the beta function caused by the edge effect of the injection bump magnets[5]. As a result, the residual dose value on the foil chamber surface was reduced to 9 mSv/h when the painting area was extended to 150 πmm-mrad in spite of 500-kW operation though it was 15 mSv/h at 400-kW operation with painting area of 100 πmm-mrad [3].

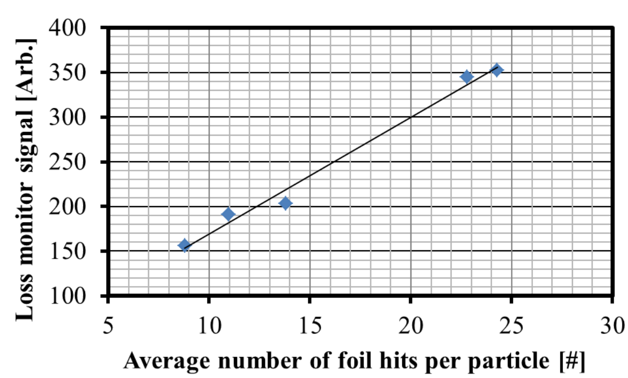

Figure 2: Beam loss signals near the injection point under different beam injection conditions in the RCS.

CONCEPT OF NEW INJECTION SYSTEM

The extension of the painting area reduced the residual activation at the injection area successfully, but it was not enough to achieve further high power operation. To reduce the worker dose near the injection area, we started to study the injection scheme to secure enough space for radiation shielding.

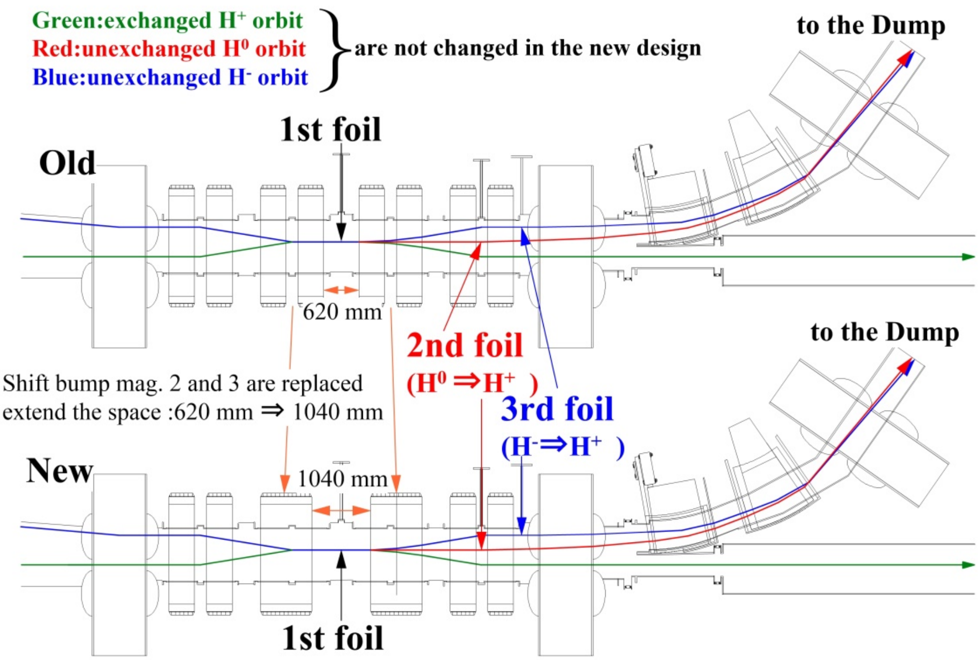

Figure 3: Layout of the present and new injection system.

Figure 3 shows the layout of the injection bump magnet. Upper figure is present configuration. In the present design, all magnet yokes of shift bump magnets are divided into half at the center. The reason is as follows.

In the charge-exchange multi turn injection scheme, two electrons of injected H^- beam are removed by the foil and injection beam becomes H^+ beam. However, some H^- particles remain H^- or H^0 on that occasion. These remaining H^- and H^0 particles must pass the other thicker foils again and becomes H^+, then those H^+ particles are led to the injection dump. The orbit of both H^- and H^0 particles have to be inside of the physical aperture of the dump line. To meet above condition, we needed to insert the second foil at the center of 4th shift bump magnet. Therefore, the magnet yokes are separated at the center and second foil is installed there. In the present design, all of 4 shift bump magnets are same form and each 2 magnets are arranged at same intervals. Herewith, when all bump magnets are excited in series by one power supply system, there is no closed orbit distortion in principle and the orbit correction becomes easy.

In contrast, two shift bump magnets before and after the foil are not separated but unified in the new design. This design allows us to secure enough space. However, if all of 4 shift bump magnet yokes are unified, the second foil is not put at the center of magnet yoke. Hence the orbit of H^- and H^0 particles are changed and those are not inside of the physical aperture of the dump line. Therefore, first and fourth shift bump magnets remain the split yoke in order to keep the second foil position, and the unified type magnets and the split type magnets are independently excited with two power supplies respectively. In this case, the orbit of H^- and H^0 particles are unchanged. We consider by the previous experiences that it is not difficult to correct the orbit distortion caused by the individuality of the two power supply systems. So far, the space between the second and third shift bump magnets is extended from 620 mm to 1040 mm.

SUMMARY

We start to design the new injection scheme which secure enough space and improve maintenability. So far, new injection system seems not impossible. However, preliminary study result indicated that temperature of the duct and shielding metals would be slightly higher. The eddy current due to the shift bump magnet field generates heat. Now we focus on studying details of such effect.

REFERENCES

[1] Y. Yamazaki ed., "Accelerator Technical Design Report for High-Intensity Proton Accelerator Project, J-PARC", KEK Report 2002-13 and JAERI-Tech 2003-44, 2003.

[2] K. Yamamoto, "Efficiency simulations for the beam collima-tion system of the Japan Proton Accelerator Research Com-plex rapid-cycling synchrotron", *Phys. Rev. ST Accel. Beams*, vol. 11, p. 123501, Dec. 2008.

[3] K. Yamamoto *et al.,* "Worker dose under high-power operation of the J-PARC 3 GeV Rapid Cycling Synchrotron", in *Proc. ICRS-13 & RPSD-2016*, FP000101, 2016.

[4] E. Yamakawa *et al.,* "Measurements and PHITS Monte Carlo Estimations of Residual Activities Induced by the 181 MeV Proton Beam in the Injection Area at J-PARC RCS Ring", *JPS Conf. Proc.,* vol 8, p. 012017, Sep. 2015.

[5] H. Hotchi *et al.,* "Beam loss caused by edge focusing of injection bump magnets and its mitigation in the 3-GeV rapid cycling synchrotron of the Japan Proton Accelerator Research Complex", *Phys. Rev. ST Accel. Beams*, vol. 19, p. 010401, Jan. 2016.

ISBN 978-3-95450-182-3