INJECTION ENERGY RECOVERY OF J-PARC RCS

N. Hayashi*, H. Hotchi, J. Kamiya, P.K. Saha, T. Takayanagi,
K. Yamamoto, M. Yamamoto, Y. Yamazaki
JAEA/J-PARC, Tokai, Ibaraki, Japan

Abstract

The J-PARC RCS is a high beam power Rapid-Cycling Synchrotron (RCS). The original designed injection energy is 400MeV, although presently it is 181MeV, and its beam power is limited to 0.6MW. Works to recover the Linac energy are ongoing and injection magnets power supplies upgrade are required in the RCS. In order to achieve 1MW designed beam power, new instrumentation are also planned simultaneously. Activities related injection energy recovery in the J-PARC RCS are presented.

INTRODUCTION

The original designed injection energy of the Japan Proton Research Complex (J-PARC) RCS is 400MeV[1]. However, currently, the machine has been operated with lower injection energy of 181MeV[2, 3]. In order to reach the design goal of 1MW beam power (8.3×10^{13} protons per pulse (ppp)), recovery of the linac energy is indispensable to reduce the space charge effect. The tune shift under present conditions, 181MeV, 0.3MW ($2.5 \times 10^{13} ppp$), the emittance $\epsilon = 216\pi mm \cdot mrad$, and the bunching factor $B_f = 0.4$, is $\Delta\nu = 0.15$. Since the tune shift is proportional to $\Delta\nu \propto \beta^{-2}\gamma^{-3}$, it decreases one half (1/2) and one third (1/3) as the energy increasing as 300, 400MeV. For 1MW, the tune shift is 0.15 in case of 400MeV, but it becomes close to 0.5 in case of 181MeV. It causes large beam loss and this is a reason why the maximum beam power is set as 0.6 MW for 181MeV.

When the injection energy set to 400MeV, the other effects are evaluated as follows. Effects of error magnetic field, except that is related to injection energy, is decrease. The field tracking of the main dipole and quadrupole field become easier. Concerning about beam loss, lost particle distribution versus scattering angle decrease to about 1/3. Local residual dose distribution may become smaller, but each lost particle energy is larger, and it is not simple whether the absolute beam loss in watt decrease.

UPGRADE OF INJECTION SYSTEM

Major components of the injection system are, four horizontal shift bump magnets (SB), four horizontal paint bump magnets (PBH), and two pulse steering magnets (PSTR) on the last part of the Linac-to-3-GeV RCS beam transport line (L3BT). Others are vertical paint bump magnets (PBV) and DC injection septum magnets. In order to reduce the space charge effect, painting injection scheme is adopted for the RCS. This scheme is to inject multi-turn and injected beam paint the phase space gradually. SB shifts the circular orbit to outer-side of the ring simply, PBH manipulates circulated beam, and the injected beam occupied intended place on the phase space. The present power supplies of the most of bump magnets will be upgraded. Whereas, the DC septum magnets can handle already for 400MeV injection designed value, it is not necessary to upgrade them.

Shift Bump Magnet Power Supply

The present power supply is IGBT (Insulated Gate Bipolar Transistor) chopper type. It is composed by multiple IGBT assemblies, and its synthetic frequency is 48kHz. One problem of this type power supply is its switching noise. This 48kHz and its higher harmonics switching noise is observed at the output current monitor and also by search coils which are set inside the magnets.

These effect on the beam was also observed. During injection period, frequency analysis of BPM signal shows $\Delta\nu = 0.2 \sim \frac{2\times 48kHz}{469kHz}$ sideband together with main revolution frequency (469kHz) spectrum. Under the special condition, which is no acceleration and the beam storage mode, SB shakes the beam and its behavior was studied by turn-by-turn mode BPM. It shows the 100kHz orbit ripple with maximum 10mm excursion. This ripple source is certainly from the power supply, but magnet (a load of the power supply) also seems to enhance the noise. Recently, four series connected magnets were measured their impedance separately. It shows that similar impedance curves with slightly different resonance frequency around 100 to 200kHz. It may cause the large orbit excursion all over the ring and further study is under investigation. Another problem is that this ripple does not have reproducibility, because the IGBT switching timing is not synchronized to the (J-PARC) system timing. The scheme adapted by the main bending magnet[5] will be applied for the SB power supply to have a reproducibility.

When this power supply will be upgraded, it is going to change power supply scheme to capacitor bank scheme which is less switching ripple. Its total current is 32kA and maximum 13kV, which consists of 16 parallel bank. Each bank will be composed of several units, which are two kinds, one takes care up and lower the current pattern and the other keeps flat-top (FT) compensating the resistance part voltage drop. It is under investigation about the

* naoki.hayashi@j-parc.jp

noise and its effect to the output current or any other things, even the number of switching is very limited. The detail is described separately[4].

Horizontal Paint Bump Magnet Power Supply

The paint bump power supply is also the same type of the present shift bump magnet, namely IGBT chopper type. But its required voltage is not as high as that of the shift bump, a faster switching IGBT assembly is adopted. Its synthetic frequency is 600kHz and fast beam oscillation is not observed, as it differ from the SB case except small COD. Since there is no effects due to the PBH PS ripple on the beam, and to perform arbitrary pattern generation this IGBT chopper type is very suitable. The first new upgraded power supply is fabricated as completely new one, and the rest of three will be modified by adding more chopper panels to satisfy its required specifications.

In general, a power supply may become less stable for lower current operation compared with its specified maximum current. The upgraded power supplies have to be used with lower injection energy 181MeV for some time, and small current situation may be required for a certain purpose. Recently, one of the power supplies got unstable during tuning for the small emittance mode. The power supply uses the current control scheme with minor voltage feedback control (ACR with m-AVR)[6]. After some investigation, it was turned out that noise from neighbor power supply enters into the this feedback loop which detect output voltage through two coaxial cables. It shows that the small current operation mode is more sensitive to the noise. Using some small trials and experiences that twist pair cable is robust against noise up to a few hundred kHz, the cables were replaced by three lines twist cable and the noise problem was solved. This scheme would be applied to the new power supply control.

Pulse Steering Magnet System

There are two main roles of the PSTR System[7], one is that switching beam size (emittance) between MR and MLF beam, and the other is that performing center injection not using painting magnet. “Center injection” means that injected beam is set the same phase space position and it is contrast mode to “painting injection”. Although this operation mode is not taken for user operation, it is necessary during the beam tuning. In case of 181MeV, the condition is fulfilled by setting larger than nominal kick angle of the injection septum. Typically required kick angle is order of 30mrad for PSTR.

For the neutron target it is better to have broader beam in order to reduce shock-wave. On the other hand, for MR, the small beam emittance is required because the physical aperture of the RCS-MR beam transport line (3-50BT). PSTR changes the horizontal orbit slope at the charge exchange foil. Typical kick angle is several mrad.

Two magnets will be installed on the last part of the L3BT line, upstream of two injection septum magnets. Concerning about the power supply, two mode, 3000A DC and 400A pulse pattern, are required.

DUMP SEPTUM COLLIMATOR

The most beam loss location is the downstream of the charge exchange foil except the collimator section. Due to multi-turn injection scheme, during the injection period, some of already circulated beam keep hitting the foil and about order of 10^{-5} particles lost due to large angle coulomb scattering before reach the collimator entrance.

In order to reduce the loss, one makes the physical foil size smaller, to minimize the number of foil hitting, but there is some limitation. If the size of foil is too small, the beam halo or tail are not converted properly and dumped to H0 dump by missing foil. Minimum vertical size is 15mm and dumped beam increase 2% compared to that of 40mm long, although it depends on the Linac beam tuning quality.

A prior to the beam commissioning, it was estimated about total $10W$ beam loss from the injection point to the entrance of the main collimator section[8]. However, the statistics was not enough, and it was not thought that these beam loss could be localized and that point becomes a residual radiation hot spot. There is no shielding blocks at there, and it is considered as uncontrolled loss. New collimator is designed to collect these losses and shield a branch vacuum duct around the H0 dump line septum magnet[10].

LEAKAGE FIELD REDUCTION AROUND EXTRACTION AREA

In the early beam commissioning in 2007, none negligible leakage field was found from the RCS extraction septum and a large dipole magnet on the extracted beam transport line (3NBT) and they are 22, 29 Gm (Gauss·m), respectively. In 2009, some magnetic field shield materials were put on the vacuum pipe. However, it is seems that an adopted method was too simple, no shield was added on the connection between the vacuum pipe or T-shape duct, which is connected to the vacuum pump. According to the beam study, the leakage field reduction was not as expected, it was about $30 \sim 40\%$ reduction[11]. Reworking plan has been launched to reduce the effect to be less than 10%, and the vacuum pipe would be re-fabricated with magnetized material and exchanged the present pipe by them.

CORRECTION QUADRUPOLE MAGNET SYSTEM

When the shift bump magnet is on during the injection period, the beta function, especially vertical beta, is strongly modified (beaten) due to edge focus effect. The beam loss due to this beta beat is estimated as not negligible amount. It is under designed that correction magnet for this problem. The number of the corrector quadrupole magnets is six and they will be installed at the beginning and at the end of all three straight section, where the space is reserved for future devices, although the space of the RCS is quite limited. The magnet will be connected to independent six pattern power supplies.

KICKER MAGNET IMPEDANCE

The kicker impedance may be one of the most serious problem to intensity upgrade[9]. The kicker is a distributed parameter type and using reflection for high field by shorting the end of the magnet. Modification to a matching type kicker would be large impact not only to the kicker magnet itself, but also for the power supply. Possible solutions may be a transverse dumper or matching at the power supply side, not in the magnet side.

Recently, the beam power is 300kW equivalent for MR beam. A beam instability is not present with normal operation, but changing chromaticity one observed instability signal. The voltage induced by the beam on powered cables is about $\sim 140V$. A conceptual design is that additional end-clipper between thyratron and load cable in oder to match impedance. Most important issue is a diode whose characteristics is high reverse break down voltage with more than 40 kV, whereas forward bias voltage is below a few 100V.

OTHER INSTRUMENTATION

As beam power increasing, further beam monitoring, especially, reduction of the beam loss becomes more important issues. An additional Ionization Profile Monitor (IPM) will be installed at dispersion free section and improvements of its electrode (for charge collecting field) structure (shape) will be done. In addition, new instruments to focus beam halo and electron cloud, and more the beam loss monitor are planned.

There are two more stripping foil beside the main foil. They convert unstriped H^- or H^0 after the first foil and certainly transport these beam to the dump. The first foil has a direct monitoring camera and mechanism to exchange a foil. However, the other foils do not have any monitoring system. It is important to have them for high beam current and long operation.

SCHEDULE

The huge Earthquake occurred on March 11^{th} 2011 damaged a lot of J-PARC facilities. The machine operation is canceled, of course. But every efforts to recover have been being made to be beam back by the end of this Japanese fiscal year (JFY), the end of March 2012[12].

Before the Earthquake, we had a plan to complete injection energy upgrade to 400MeV in JFY2012. Further intensity upgrade, namely 50mA RFQ installation was planned in JFY2013 and later. After the Earthquake, completion of both upgrade projects postponed to JFY2013. There is a still uncertainties but this is current plan.

Above each item will be installed as soon as they are ready to install. The most important and large one is the Shift Bump magnet power supply. Its installation and tuning requires a relatively longer period, then its installation is planned in the last JFY.

SUMMARY

In the J-PARC, efforts to recover the Linac designed energy, is on going. At the same time, upgrade plans progress at the RCS. The Shift Bump and Horizontal Paint Bump magnets power supplies will be upgraded and the Pulse Steering magnet system will be installed as new knob. Various experience has been collected since the first beam commissioning of the RCS in 2007. Using also these experience, required items and necessary plan is under consideration for the design goal of 1MW beam power. These issues and upgrade items will be realized gradually and completed in JFY2013, adjusted with the effect of the Earthquake.

REFERENCES

[1] Y. Yamazaki eds., Accelerator Technical Design Report for High-Intensity Proton Accelerator Facility Project, J-PARC, KEK-Report 2002-13; JAERI-Tech 2003-044.

[2] H. Hotchi, et al., "Beam commissioning of the 3-GeV rapid cycling synchrotron of the Japan Proton Accelerator Research Complex" *Phys. Rev. ST Accel. Beams* 12, 040402 (2009)

[3] H. Hotchi, "J-PARC Beam Commissioning Progress" in this Proceedings.

[4] T. Takayanagi, et al., "Upgrade Design of the Bump System in the J-PARC 3-GeV RCS" in this Proceedings.

[5] Y. Watanabe, et al., "Suppression Scheme of COD Variation Caused by Switching Ripple in J-PARC 3GeV Dipole Magnet Power Supply" *Proceedings of IPAC'10*, p.3242-3244., Kyoto, Japan (2010)

[6] T. Takayanagi, et al., "Development of Large Current High Precision Pulse Power Supply" *IEEJ Trans. IA* **D 127** p.813-p.821 (2007) (Japanese)

[7] T. Takayanagi, et al., "Design of the Pulse Bending Magnet for Switching the Painting Area between the MLF and MR in J-PARC 3-GeV RCS" *Proceedings of IPAC'10*, p.3293-3295., Kyoto, Japan (2010)

[8] P.K. Saha, et al., "Realistic Beam Loss Estimation from the Nuclear Scattering at the RCS Charge-exchange foil" *Proceedings of EPAC 2006*, p.333-335., Edinburgh, Scotland (2006)

[9] Y.HM. Chin, et al., "Impedance and Beam Instability issues at J-PARC Rings" *Proceedings of Hadron Beam 2008*, p.40-44., Nashville, Tennessee, USA (2008)

[10] K. Yamamoto, et al., "Foil Scattering Loss Mitigation by the Additional Collimation System" in this Proceedings.

[11] M. Yoshimoto, "Suppression of Leakage Fields from DC Magnets in J-PARC 3GeV RCS" in this Proceedings.

[12] K. Hasegawa, "Status of J-PARC Accelerator Facilities after the Great East Japan Earthquake" in this Proceedings.