PRESENT STATUS OF INJECTION AND EXTRACTION SYSTEM OF 3GEV RCS AT J-PARC

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Abstract

The development of injection and extraction system for 3GeV RCS (Rapid Cycling Synchrotron) at J-PARC (Japan Proton Accelerator Research Complex) has many challenging issues as it stores MW beam in the ring. Components in the injection and extraction area, such as DC and pulse magnets, the charge exchange system, beam monitors, titanium and ceramic vacuum chamber, and beam dump are to be properly designed so as to meat their design goals. Designs of components have been finalized while tests and experiments of some components are being carried out. In this paper, summary of the injection and extraction system design together with the recent status of developments, and beam operation scheme for beam injection and extraction are reported.

INTRODUCTION

The J-PARC accelerator complex, which is now under construction, [1] consists of a 400MeV linac (LINAC), a 3GeV rapid cycling synchrotron (RCS), and a 50GeV main ring synchrotron (MR). Main components are manufactured and tested, and the beam commissioning will start from September 2007.

The RCS is designed to accelerate the H^+ beam from 400 MeV to 3 GeV, respectively with 8.3×10^{13} protons per pulse at 25 Hz repetition rate. Thus it realizes a 1 MW, 40 kJ proton source. At the first stage, the beam is injected from a LINAC with 181 MeV energy. The RCS boosts up the beam power to 0.6 MW through accelerating the proton from 181 MeV to 3 GeV at a 25 Hz repetition rate. In the second stage, the beam energy injected from the LINAC will be upgraded to 400MeV and then, RCS realizes 1 MW proton beam. Consequently, the hardware of the RCS has been originally designed to accept 400 MeV beam injection from the first stage.

The RCS at the J-PARC serves not only as an injector for the MR but also as a spallation neutron source for the materials and life science facility (MLF). The proton beam extracted out of the RCS is divided into two beam-lines from the MR and the MLF using a pulsed bending magnet. However, the required beam parameters for the MR and those for the MLF are different. The RCS is designed to satisfy these requirements through changing the injection scheme in each individual repetition.

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BEAM INJECTION AND DUMP SYSTEM

Figure 1 shows the schematic diagram of the beam injection and dump system at the RCS. The H^- beam from the LINAC is injected into the RCS ring and the charge is changed from H^- to H^+ with a charge exchange foil. The injection point at the foil can be controlled using two injection septum magnets (ISEP) and two pulse steering magnets (PSTR). The ISEP are operated DC but the PSTR operation mode is changed in every repetition. A bump orbit for the beam injection is made using ten bump magnets, which are classified into three groups according to their operation mode as follows; four horizontal shift bump magnets (SBHM), four horizontal paint bump magnets (PBHM), and two vertical paint bump magnets (PBVM). The SBHM and PBHM are installed in the ring and make the closed bump orbit. However, the PBVM are located in injection beam transport (L3BT) line and steer the injection point on the vertical phase space during the beam injection.

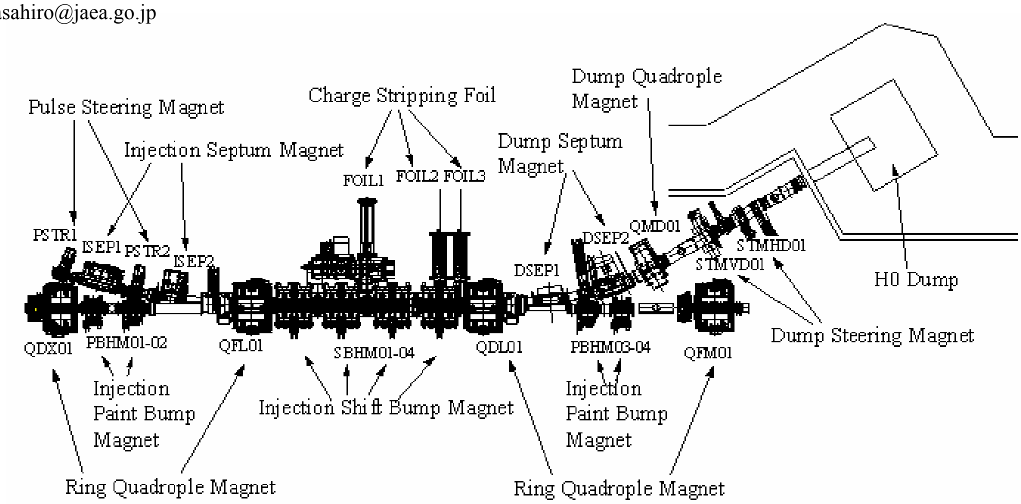

Figure 1: The schematic diagram of the beam injection and dump system at the RCS.

Injection Scheme

During the beam injection into the RCS, the SBHM produce a fixed bump orbit which is located at 90 mm and 0 mrad on the horizontal phase space. On the other hand, the PBHM steer the bump orbit, so that the beam emittance can be controlled with a uniform distribution. In the normal operation when the painting emittance in the ring is 216π mm-mrad, the bump orbit is changed from (131 mm, -6.3 mrad) to (90 mm, 0 mrad), whereas the injection beam emittance is 6π mm-mrad. The designs of the all bump magnets are finished and a prototype of SBHM is manufactured and tested at JAEA [2][3].

There are different beam parameters required from the MR and the MLF. One is the beam emittance extracted from the RCS. The beam aperture of the MR is limited to 54π mm-mrad or less since the acceptance of a 3-50BT collimator. On the other hand, the MLF has a large beam acceptance and it requires the beam aperture as large as possible, in order to avoid high power density proton beam colliding with the neutron target to cause serious damage. In the first stage, the beam emittance extracted from the RCS is 54πmm-mrad reduced from 216π mm-mrad after the beam acceleration to 3GeV. However in the second stage, the beam injection energy is upgraded to 400 MeV to realize the extraction beam emittance of 81π mm-mrad, which makes it difficult to inject the beam into the MR. Thus the paint beam emittance needs to be decreased to 144π mm-mrad for the MR. The RCS can optimise the paint area for the MR and the MLF. The SBHM, PBHM, PBVM, and PSTR can be tuned to control both the bump orbit and the injection point in a pulse-to-pulse based operation. The PSTR take another important part in the 400 MeV beam injection. When the beam is injected without painting operation, the ISEP2 is required to increase the magnetic field strength to 0.68 T, which results in the loss of injected H^- beam due to Lorentz stripping. In order to decrease the field of the ISEP2, the PSTR have to be operated. The designs of the ISEP are completed and the manufacturing of them has been started [4][5]. The PSTR are designed but are not installed at the first stage because their power supplies will not be ready at the first stage.

Charge Exchange System

The charge exchange system also has many challenging issues. One is the development of the foil. The charge exchange foil is required both ultra thin thickness and high charge exchange efficiency. In the RCS, the foil is made of 290 μg/cm^2 thick carbon to achieve the charge exchange efficiency of 99.7%. In order to prove its long lifetime with mechanical strength against high temperature of 1800K due to high-energy deposition, the irradiation experiments are now being carried out using 3.2MeV N^+ DC beam of 2.5 μA and 750keV H^- DC beam of 500 μA in RLNR and KEK, respectively [6][7].

Another problem is the complicated structure. The charge exchange system is composed of many elements and they are located in the same vacuum chamber. Figure 2 shows the cross section of the vacuum chamber for the charge exchange system.

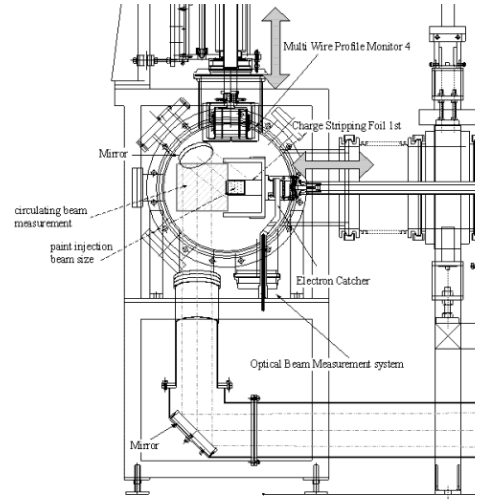

Figure 2: The cross section of the vacuum chamber for the charge exchange system.

The charge exchange foil is required to be replaced with the spare one remotely and automatically in vacuum. Thus the foil is glued on a module frame, a rack put into many of these modules are installed on the adjacent vacuum chamber, and the module is clamped and moved by the transfer rod. When the foil is damaged and becomes unoperational, the module is replaced with the spare one by the transfer rod in vacuum.

The injection point of the H^- beam is measured using the multi wire beam profile monitor (MWPM4) before the foil is set. The MWPM4 have tungsten wires of 0.1mm diameter with 3mm pitch. In the design of the MWPM4, the wires are glued obliquely to realize a higher resolution profile monitor by scanning the oblique wire used as wire scanning monitor.

When the beam injection point is fixed by adjusting the ISEPs and PSTRs, the injection beam profile can be measured by the MWPM4. However after the foil is set, the beam injection point can't be measured, because the MWPM4 is pulled out. Thus in order to observe the beam position during exchanging the charge of H^- beam, an optical beam observation system is introduced in the charge exchange system. The luminescence from the foil collided with the high energy beam is observed directly through a light guide composed of lenses and mirrors to a CCD camera set on the utility tunnel where is low level of radiation absorbed dose.

Electrons are stripped from the H^- beam at the foil. Revomal of electrons with an electron catcher is required to reduce beam loss in the high intensity proton beam. In the RCS, the stripped electrons are trapped to fringing field from the SBHM, where the field strength is about 200Gauss in the 181 MeV injection and the Larmor radius is about 50cm. Therefore the electron catcher made of a carbon block is decided to be installed, and it is being designed in detail.

H^0 Dump and Dump Line

When the 1 MW proton beam is extracted from the RCS, H^0 and H^- beam of 0.4kW are produced from the H^- beam passing through the charge exchange foil. In the case that the carbon foil is damaged, the H^- beam is not charge exchanged properly at the foil and the H^-/H^0 intensities increase even further. Thus, the control of the beams of H^0 and unchanged H^- is important. There are two more carbon foils installed downstream of the 1st foil. At the 2nd and 3rd foil, the H^- beam and H^0 beam are exchanged to the H^+ beam again respectively. The dump beams including the two types of H^+ beams passes through the dump line and directs to the H^0 dump.

There are two H^+ beam lines from 2nd foil and 3rd foil, so called H^- line and H^0 line, respectively. The dump line is designed to satisfy the beam apertures for both H^- and H^+ lines. There are many magnets to deflect and focus the two beams as follows: two dump septum magnets (DSEP), a dump quadrupole magnet (QMD), horizontal and vertical steering magnets (STMVD, STMHD). All of the magnets located in the dump line have a large horizontal aperture. The designs of all magnets are finished and they are manufactured now.

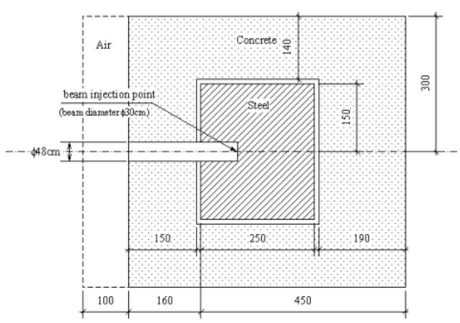

Figure 3: The cross section of the H^0 dump.

The H^0 dump consists of a steel block implanted in a concrete wall as shown in figure 3. It is designed to absorb the dumped beams up to a total beam loss of 1 kW, and has already been constructed. The upgrade of its acceptable beam loss to cope with possible stripping foil troubles is underway. Based on the thermal boundary condition, the original model can accept the total beam loss of 5 kW. But it has almost no tolerance against the radiation activation to the ground behind the dump. The H^0 dump is modified to accept larger beam loading by adding a 40 cm long iron peace into the H^0 dump hole, which can absorb the total beam power up to 4 kW.

BEAM EXTRACTION SYSTEM

The circulating beam in the RCS is extracted using kicker magnets (KM) and extraction septum magnets (ESEP) to the MR and the MLF. After the proton beam is accelerated to 3 GeV energy, the circulating beam is transferred to the beam extraction orbit by the KM and is deflected to the extraction beam transport line by the ESEP. Figure 4 shows the schematic diagram of the extraction system at the RCS. In order to achieve the designed high repetition rates of the RCS, the KM are required sweep the field at repetition rate as fast as 25Hz with the short rise time of 350 μs. In the mean time, the ESEP are operated in DC. They are required to produce high magnetic field for deflecting the 3 GeV high energy beam at the total angle of 16.5 degree. All the magnets have wide apertures to avoid the beam loss. Therefore, the KM are installed in the vacuum chamber. All KM and vacuum chambers have been assembled, and the each magnet is being tested [8][9].

The beam dump for 3 GeV RCS (3GeV Dump) is located at the 3 NBL line. The circulating beam is not absorbed by the 3 GeV beam dump, if the extraction system is not ready. Therefore, at the first step of the beam commissioning operation in the RCS, namely before the operation of the KM, the beam is deflected to the ESEP with extraction DC magnets (KMDC), which are installed near the kicker magnets. The KMDC bend the beam, which goes through one third the ring from the injection section to the extraction section. The KMDC have been manufactured, and the final ESEP design will be completed soon.

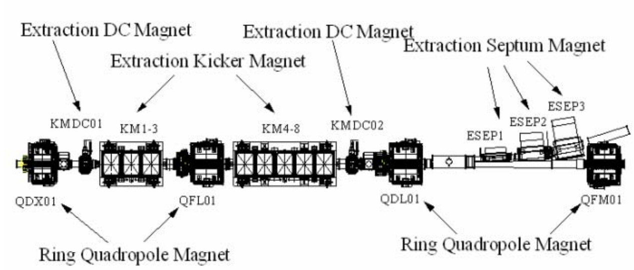

Figure 4: The schematic diagram of the beam extraction system at the RCS.

CONCLUSION

The designs of the injection and extraction system of the RCS are nearly completed, and almost all components have been manufactured and being tested. Detailed study for the beam commissioning on the beam injection and extraction is starting.

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