STATUS OF INJECTION ENERGY UPGRADE FOR J-PARC RCS

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Abstract

The injection energy upgrade for J-PARC RCS is planned in 2013. This includes the power supplies upgrade of injection pulse magnet systems, suppression for leakage field, quadrupole correction magnets, reduction of kicker impedance effect and improvements of beam diagnostic instrumentation. The paper reports the present status.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) RCS (Rapid-Cycling Synchrotron) provides high intensity protons for various experiments of the Material and Life science Facility (MLF) and works as a booster of the MR (Main Ring) [1]. The RCS is originally designed as 400 MeV injection to supply 1 MW beam power with 8.3×10^{13} ppp (protons per pulse) and 25 Hz. However, it has been operated with lower injection energy, 181 MeV, since the initial start up in 2007 [2]. Presently, the RCS can provide 300 kW beam power with 2.5×10^{13} ppp and the tune shift is $\Delta\nu = 0.15$.

What limits the beam power is the Linac beam current of 15 mA. If the beam current increased to 30 mA, the beam power would be 0.6 MW. But the tune shift also increase and it may cause large beam loss. With 400 MeV injection, and 50 mA, the tune shift is the same as the present number. It would be realistic to reach the goal of 1 MW beam power.

The injection energy upgrade had planed in 2012. However, after the earthquake, the priority was set to recover the facility and energy upgrade projects have been postponed to 2013. The J-PARC, including the RCS, was recovered from the earthquake damages in the end of 2011 and now it is running user run [3]. In this paper, it describes the status of RCS injection energy upgrade and progress since the last year [4].

RCS INJECTION SYSTEM

The injection system of the J-PARC RCS is described elsewhere [2]. The major components to be upgraded are two bump systems' power supplies, and newly installed Pulse STeeRing magnet (PSTR) system. Injection and dump septum magnets power supplies were fabricated to fulfill 400 MeV injection requirements.

Shift Bump Magnet Power Supply

This Shift Bump magnet (SB) power supply is one of the most important upgrade items [5]. The present supply consists of multiple IGBT (Insulated Gate Bipolar Transistor) assemblies to perform an arbitrary current pattern. But it generates large switching noise and it affect the beam [6].

New power supply was designed based on a capacitor bank scheme and it has fewer switching times to generate a trapezoidal current pattern. Maximum required current is 32 kA and voltage is 14.4 kV (±7.2 kV) defined from the magnet inductance and fast rise/fall time of 150 μs. The new power supply consists of 16 banks in parallel. One bank can take 2 kA and has 12 rise-fall units and 2 flat-top units. They contains many aluminum electrolytic or film capacitors. The rise-fall units are used increasing or decreasing (ramping) the current within pre-defined period. The flat-top units are used to hold the current longer than 500 μs (injection period) to compensate the voltage drop due to resistive impedance. These units are connected in series inside the bank. IGBT switches in these units control which units (capacitors) to be connected to the main circuit, its polarity and its timing.

Figure 1 shows the first bank output current (2 kA) and output voltage with different rise/fall time (150 μs and 500 μs). Large ripple are observed at switching. At the last part of current fall period, "slow down mode" prevents the current goes undershoot to negative polarity. The flatness of output current precision within $\pm$ 0.2 % has been achieved longer than 500 μs flat-top period. These voltage and current ripple should be minimized. At least it has to be evaluated its effect on the beam. It is also important to check the reproducibility and the precision for the MLF and the MR pattern and between their switching. Before the final installation in 2013, it is plan to check operation with multi banks, up to all 16 banks parallel with low repetition.

Horizontal Paint Bump Magnet Power Supply

The horizontal paint bump magnet (PBH) power supply is an IGBT chopper type. It is suitable to generate an arbitrary current pattern which is necessary for this apparatus. In 2011 the most powerful one has been replaced and its maximum current increases from 17.6 to 29 kA. The number of chopper panels increased from 3 to 9, and its feedback line is improved by replacing two coaxial cables with a shielded twisted tree-wire. Figure 2 shows two sets of typical current patterns whose peak current of 10 or 29 kA.

The new PBH1 power supply is stable and used for the normal operation. Rest of horizontal painting magnet power supplies will be upgraded in 2012 summer shutdown. The number of chopper panels increases from 2 to 7 and the output voltage doubled from ±0.6 kV to ±1.2 kV.

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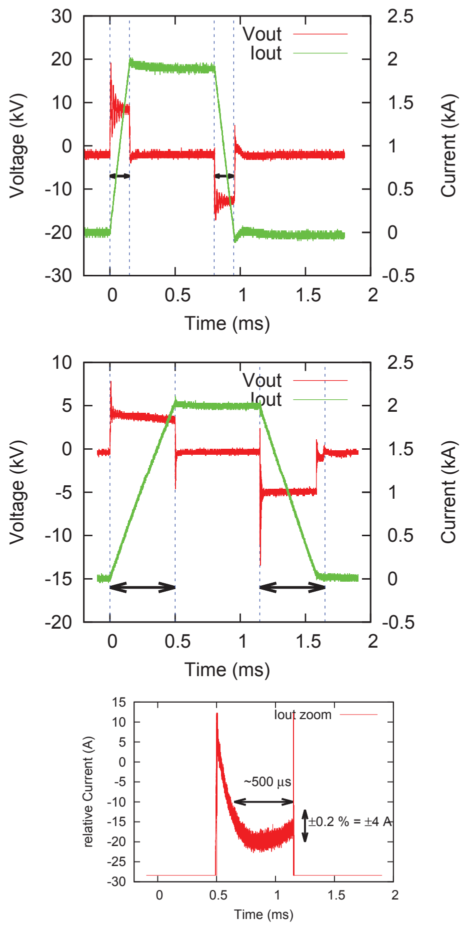

Figure 1: The output current and voltage pattern of new SB PS one bank. The upper is for 150 μs rise/fall, and the lower is for slower rise/fall time (500 μs). The bottom one shows good flatness of the current.

Pulse Steering Magnet System

The PSTR system has two important roles. One is switching painting area for the MR and the MLF, and the other is realizing the center injection at 400 MeV. The required bending angles are quite different between them, a few mrad and order of 30 mrad, respectively [7]. Therefore, its power supplies have two operation modes. The former is operated with pulse mode, and the latter is realized in DC mode. The DC mode allows the current up to 3000 A, typically 1800 A. The pulse mode gives trapezoid current pattern with maximum flat top current of 450 A. The rise or fall time of the current is from 0.5 to 1.5 ms.

The power supply scheme of the DC mode is similar to the extraction septum auxiliary power supply. That of the pulse mode consists of two kinds of units, a rise-fall unit, and flat-top units, as same as the new SB power supply. The difference is that each unit has two independent circuits and capacitor bank for the MR and the MLF. Because required voltage is not as large as that of the SB power supply, one unit can handle it. The present feedback system seems too strong and switching between the MR and the MLF mode,

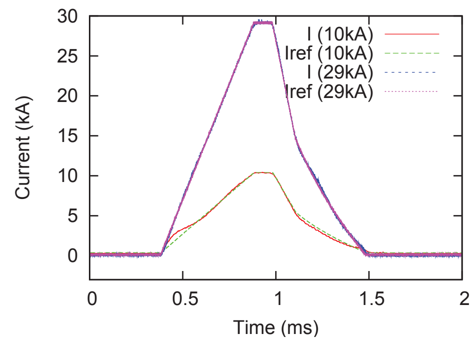

Figure 2: Current pattern of new PBH1 power supply. In case of 29 kA and 10 kA, with reference current pattern and monitoring current.

the first shot has slightly large current. Further investigations are necessary. Long term stability and reproducibility of the power supply are going to check together with field measurement.

The magnet center field becomes 0.25 T with the current of 1600 A, and a field mapping has been done. The integrated field BL homogeneity are within $\pm 1\%$ in range of ± 100 mm horizontal plane. The field measurements and mapping with pulse mode is underway.

The magnet will be installed in summer 2012. A ceramics vacuum chamber will be used. There is one concern about high residual radiation spot on the present chamber. It is presumably due to H^+, H^0 stripping from H^- beam. The vacuum pressure at this section should be improved.

LEAKAGE FIELD TREATMENT AT EXTRACTION AREA

There are two sources of DC field leakage around the RCS extraction area. One is from the RCS extraction septum and the other is from the bending magnet at the 3NBT (3-GeV-to-Neutron target Beam Transport) line. Both were estimated by the beam as 1.4×10^{-3} and 1.8×10^{-3} Tm, respectively. Additional shield covers have been put on the vacuum chambers and reduce about $30 \sim 40$ % [8]. But they were only put where applicable. T-shape ducts or connecting flanges were left uncovered. However, it still needs to improve the leakage field suppression. Reworks have been planed separately for each source.

Since the residual field due to the 3NBT magnet is relatively small magnetic field but leakage section is rather long. Two kinds of magnetic material, SUS430 and permalloy PC, are adopted to re-fabricate these chambers and bellows. Necessary heat treatments for vacuum or magnetic characteristics were also studied. Shielding effect less than factor 10 are confirmed upto 0.0020 T as external field [9]. Rework strategy at the Extraction septum is still underway. The important is that new additional shield should not affect the main quadrupole magnets. So, it is not simple to add something close to the quadrupole magnet.

KICKER IMPEDANCE TREATMENT

The kicker is a dominant impedance source in the RCS and it may cause a beam instability. If the chromaticity is fully corrected, the horizontal instability occurs. But it is not observed in normal operation (up to 2.5×10^{13} ppp).

The kicker is a distributed parameter type and using reflection in order to get high field by shorting the end of the magnet. A conceptual idea is that put a matching element between thyratron and load cable. Here, a key device is a diode. Its characteristics must be high reverse voltage 40 kV, and take high current 3 kA, whereas it should "turn-on" at small forward voltage. Because an induced voltage by the beam is not so high, and the originally tested diode was not "turn-on". It was tested how the induced voltage was reduced with new diode (Figure 3). In the ideal case ("R-only"), the matched resistor is directly connected to the power output coaxial cables. When the cable is left "open", maximum reflection occurs. "Diode+R" indicates that new diode and the matched resistor were connected. The impedance becomes about half [10]. But it might require further suppression of the impedance. Even though it is effective to reduce the impedance by adding this diode and the resistor, it increases reflection when thyratron is on. It is important to do feasibility test of the kicker power supply after adding these elements.

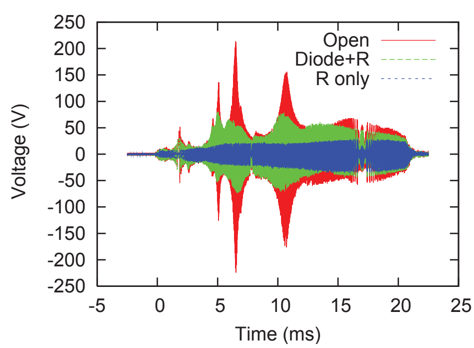

Figure 3: The induced voltage by the beam observed at the kicker power supply with various conditions.

The situation is the same up to 3.5×10^{13} ppp with the Linac current of 20 mA. The current may increase up to 30 mA in later this year. The situation of instabilities continues to be updated. There is a possibility that the space charge effect may works to stabilized the beam even at 1 MW.

IONIZATION PROFILE MONITOR

There are two Ionization Profile Monitor (IPM) of the vertical and the horizontal plane at the first arc section. It is useful for practical usage, but there is a large systematic position error. Its charge collection electric field is distorted, because its electrode length along the beam axis is too short (less than 300 mm) even the physical aperture is quite large about 297 mm in diameter. In order to solve this problem, new electrode structure were re-designed by 3D simulation tool. Further, it is important to measure the horizontal beam profile at the dispersion free area. The third IPM is fabricated and will be installed in 2012. Electrodes of two present IPMs also will be replaced [11].

QUADRUPOLE CORRECTOR

Within limited conditions, it is possible to manipulate the tune dynamically by adjusting the main quadrupole magnet setting [12]. However, it is not so flexible, it is better to have an independent system. There are six points for new devices between the straight and the arc section. It plans to install a set of quadrupole correction magnets at there. As the first step, we focus to correct the SB edge focusing effect by using this system. The magnet would be made with full specification. On the other hand, the power supply would be made with minimum requirements.

SCHEDULE AND SUMMARY

It is presented the status of the J-PARC RCS injection energy upgrade. One upgraded power supply for PBH1 were already installed in 2011 and has been working well. In 2012 summer shut down, the PSTR system will be installed and the rest of all PBH power supplies will be upgraded for 400 MeV injection. Leakage field from 3NBT will be suppressed by better shielding. New IPM will be installed together with new IPM electrode. In 2013, it is planed to have longer maintenance period of five months. During this time, the new SB power supply will replace the present one. 12^{th} RF cavity is also planed to install at this time. In addition, the postponed re-alignment works are scheduled in this period. Because the RCS could run with minimum beam loss at this beam power, even though the main magnets were moved 7 mm at maximum due to the earthquake [13]. A beam commissioning of 400 MeV injection plans to start the end of 2013 and the user operation is resumed in early 2014.

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