PROGRESS OF INJECTION ENERGY UPGRADE PROJECT FOR J-PARC RCS

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Abstract

The injection energy of the J-PARC RCS will be upgraded in the beginning of 2014. A power supply of the shift bump magnet will be replaced during the long shut down in 2013. Some of other systems, the paint bump power supplies and pulse steering systems, were already upgraded, tested and used for the nominal user operation. The paper reports the progress of injection energy upgrade project.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) is a multi-purpose research center which consists of three accelerators and three experimental facilities [1]. The RCS (Rapid-Cycling Synchrotron) is the second accelerator to provide 1 MW beam power for a Spallation neutron source target, the Material and Life science Facility (MLF), and works as an injection booster for the Main Ring (MR). The designed injection energy of the RCS is 400 MeV, but it has been operated with 181 MeV since 2007. With the present lower injection energy, the RCS provides 0.3 MW beam power for the MLF. The injection energy upgrade upto 400 MeV is an important step to achieve the original design of 1 MW together with higher beam current Linac front-end. In this paper, it describes the status of RCS injection energy upgrade and progress since the last year [2].

RCS INJECTION SYSTEM

The injection system of the J-PARC RCS is described elsewhere [3]. The RCS injection system consists of four DC septum magnets and several bump (pulse) magnets. While power supplies for the septum magnets were fabricated to satisfy the parameters of 400 MeV, various bump magnets power supplies were optimized for 181 MeV and they have to be upgraded. Until 2012, pulse steering magnet (PSTR) system was installed and horizontal paint magnet (PBH) power supplies have been upgraded. The rest of major one is the power supply for the shift bump (SB) magnet. In addition, the vertical paint magnet (PBV) power supply should be upgraded in later.

The horizontal painting is realized by time dependent bump orbit established by four horizontal paint magnets. In order to switch the horizontal painting area between the MR and the MLF mode, not only PBH but also both SB and PSTR parameters have to be changed simultaneously. The horizontal injection point is kept the same, because the stripper foil is fixed. Whereas, the slope of injection orbit differs between two beam modes. For vertical painting, two smaller magnets in the injection beam transport line control vertical angle at the injection point.

Pulse Steering Magnet System

The PSTR magnets and their power supplies were successfully commissioned in 2012. Two magnets were installed in the L3BT (Linac-to-RCS) line, up- and downstream of the Injection Septum 1 (ISEP1). Because of pulse mode, ceramics duct is used as their vacuum chambers. They are necessary to switch painting area between the MR and the MLF mode. The other purpose of the PSTR is to perform so-called center injection (no-painting) at 400 MeV. In case of 181 MeV, it is possible to do center injection without the PSTR, but instead requiring more current on injection septum 2 (ISEP2).

Because its required kick angle for the nominal (pulse) or the center injection (DC) is quite different, the power supply consists two parts, a DC and a pulse power supplies. The DC power supply allows the current up to 3000 A, and the pulse power supply gives trapezoid current pattern with maximum flat top current of 450 A. The part of the pulse mode consists of two kinds of units, a rise-fall unit, and flat-top units. It is the as same scheme as that of the new SB power supply described in later.

A stability between the MR and the MLF mode was an issue. The first shot of the MR consecutive pulses has slightly larger current compared with other shots. With the real condition, typical MR cycle is 6.0 s (slow extraction), or 2.48 s (fast extraction) and this period was also related to the excess of the current peak. The problem found was due to charged voltage stability of the main capacitor. It does not recover its originally setting value within 40 ms.

Since there are the dedicated capacitors for the MR and the MLF mode, during the continuous MLF shots, the MR capacitor has enough time to recover the originally set voltage. While the MLF capacitor is always slightly lower voltage compared with the original setting. In order to solve this problem, a small DC power supply which is used for charging the main capacitor was investigated. Its control method, the charge sensing port was revised and improved [4].

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Before the magnet installation, field mapping was taken both pulse and DC mode. The leakage field of PSTR2 to the ring orbit was concerned. The leakage field was actually measured with 3000 A. It turned out that the effect was small (kick angle of 0.27 mrad) and it became even smaller due to neighbor PBH2 acts as shielding. The effect was evaluated with the beam and it was 0.08 mrad with 3000 A. With nominal operation is less than 400 A, it is negligible. In order to demonstrate center injection at 400 MeV, by limiting ISEP2 current lower and using the PSTR, the orbit was established. The real horizontal painting switching between 150 and 100 π mm mrad for the MLF and the MR were also performed. The commissioning of PSTR with the beam was successful [5].

Paint Bump Magnet Power Supplies

The paint bump magnet (PB) power supply is an IGBT chopper type. It is suitable to generate an arbitrary current pattern which is necessary for this apparatus. In 2011, PBH1 had been replaced, which is the most powerful ones in PBH PS and its maximum current increases from 17.6 to 29 kA. The rest of power supplies for PBH2,3, and 4 were upgraded in 2012. Their maximum currents and voltages are 23.4 $\sim$ 21.0 kA and $\pm$1.2 kV. Vertical paint magnets power supplies will be upgraded in later.

Shift Bump Magnet Power Supply

The rest of major apparatus is the Shift Bump magnet power supply. It was designed on a capacitor bank scheme to generate a trapezoidal current pattern. Maximum output current and output voltage are 32 kA and 14.4 kV ($\pm$7.2 kV) to establish fast rise/fall time of 150 μs. The four magnets are connected in series and its inductance including current feeder is about 57.7 μH.

The new power supply consists of 16 banks in parallel. One bank can take 2 kA and has 12 rise-fall units (6 units each for plus and negative bias with respect to the ground) and 2 flat-top units. They contains many aluminum electrolytic or film capacitors (24 mF $\sim$ 192 mF). The rise-fall units are used ramp-up or down the current within pre-defined period. The flat-top units are used to hold the flat-top 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.

In order to switch between MR and MLF waveform, one pair of rise-fall units is assigned for MR or MLF each. The rest of units are commonly used for both modes. A design of the flat-top unit was revised so that it has two individual circuits for each MR and MLF modes inside the unit.

Figure 1 shows the large ringing of output voltage and current during the rise-fall single unit test. The situation was the same for one bank test. A schematic diagram of one unit is shown in Fig.2. The resonance frequency was changed from 60 kHz to 90 kHz, if the snubber C_{sn} was changed from 16 to 8 μF. During the current ramp-up period, U- and Y- IGBT are on, and the output current goes through them. No current flow through X- and Y-IGBT,

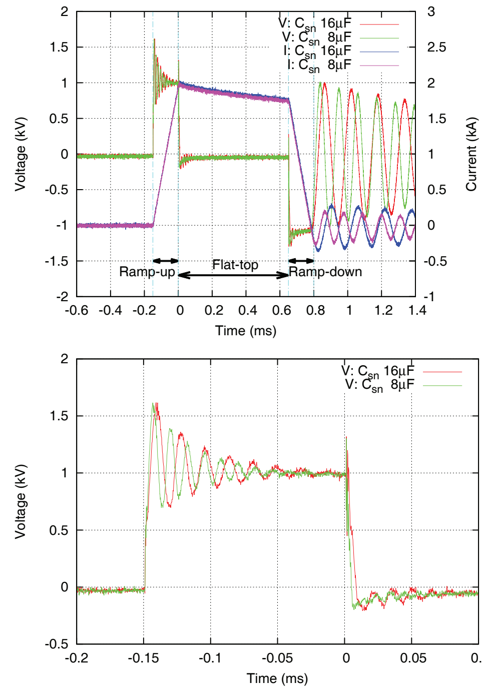

Figure 1: The output voltage and current waveform of single rise-fall unit. Lower plot is zoom of the output voltage during the current ramp-up period. The dependence of snubber capacitance is observed.

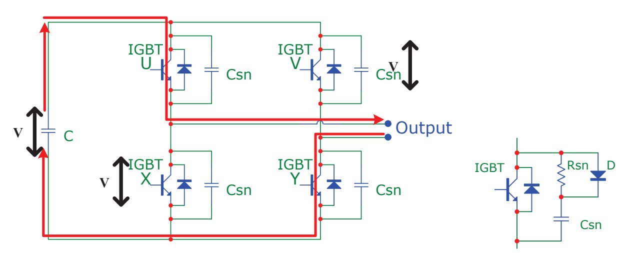

Figure 2: The circuit diagram model of the unit. There are four IGBTs, switching device, and its snubber circuit to prevent over voltage on IGBT. The left-side C is a main capacitor (24 mF) and it can be considered as DC battery during a few ms. Right one is a RCD snubber circuit.

but voltage across them increase (Fig. 2). In this way, the snubber C_{sn} resonates with the parasitic inductance (about 1 μH). Similarly, during the ramp-down, all four IGBT are off and current flows X- and V- IGBT diode and there is voltage across U- and Y- IGBT. In the end of the ramp-down, the energy stored in U- and Y-C_{sn} couple with the large load inductance. The RC snubber might be good if one does not care the last of current ramp-down. Finally, the RCD snubber is considered. Its advantage is that it works as RC snubber during charging energy in C_{sn}, but it takes longer discharge time because the resistor limits the current (Fig.3). Figure 4 shows the result of internal impedance measurements. In case of C snubber, it shows a sharp resonance at 50 kHz. In case of RCD snubber, snub-

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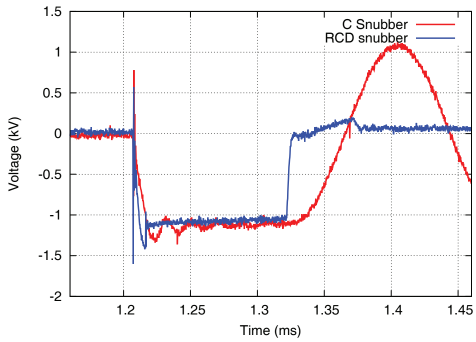

Figure 3: An output voltage comparison with C-snubber or RCD-snubber during the current ramp-down period.

ber $R = 33\ \Omega$ is seen as a flat-part[1].

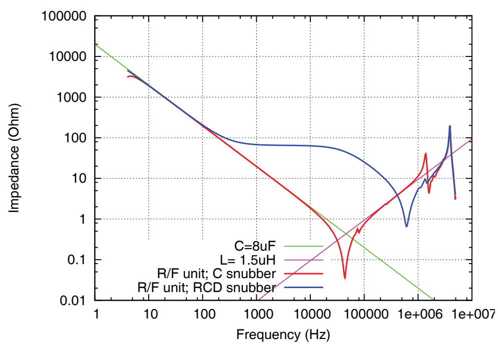

Figure 4: The internal impedance of the rise-fall unit. Temporary, small DC power supplies to charge the main capacitor were removed.

Figure 5 is similar to Fig. 1, but it is for the one bank. The ringing of $50 \sim 60$ kHz is due to rise-fall unit. Higher frequency of 500 kHz could be damped by adding resistor at the output terminal of the bank. In further, multi-bank test or stability check during switching between the MR and the MLF mode, like PSTR, is in progress.

OTHERS

Concerning leakage field reduction in the extraction area, an effect of the 3NBT error source was reduced and beam study shows an improvement. The source of the extraction septum is under consideration. Quadrupole corrector and its vacuum chambers were designed [6], and they will be installed also in 2013. The kicker impedance dominates in the RCS and its effect and cure to reduce it are under consideration [7].

SCHEDULE AND SUMMARY

It is presented the status of the J-PARC RCS injection energy upgrade. In 2012, the PSTR system, magnets and power supplies, was installed and successfully commissioned. The rest of all PBH power supplies were upgraded for 400 MeV injection. In 2013, the user run continues until the end of July and it is planed to have longer maintenance period of five months. During this time, the new SB power supply will replace the present one. A beam commissioning of 400 MeV injection plans to start the beginning of 2014 and the user operation is resumed. Further, Linac front-end upgrade (50 mA) is planed in 2014 summer [8], and high power test of 1 MW becomes possible after that.

[1] In fact, the rise-fall unit is two circuits in series. These numbers are slightly different with Fig.4.

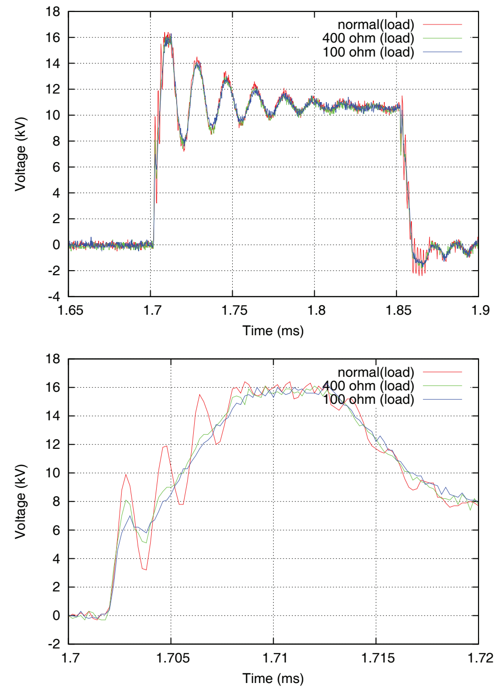

Figure 5: The output current and voltage pattern of one bank. Higher frequency ringing (400 kHz) is damped by adding resistor parallel to the output port. Lower plot is zoom of upper plot.

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