

# NEW INJECTION BUMP POWER SUPPLY OF THE J-PARC RCS\*

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## Abstract

The new injection bump power supply for the shift bump (SB) magnet of the beam injection sub-systems at the J-PARC (Japan Proton Accelerator Research Complex) [1] 3-GeV RCS (Rapid Cycling Synchrotron) [2] has been developed and manufactured. The power capacity of the new power supply was more than doubled with the injection beam energy upgrading of the LIANC (Linear Accelerator) from 181 MeV to 400 MeV [3]. Furthermore, the low ripple noise on the output current was required to prevent the resonance of the RF shield loop at the ceramic duct with the excitation magnetic field [4]. The power supply newly adopted a capacitor commutation method to form the trapezoid waveform pattern (bump waveform). This paper reports characteristic about the new power supply.

## INTRODUCTION

The new power supply for the injection SB-magnet, which is one of the beam injection sub-systems of the 3-GeV RCS in the J-PARC, has been developed and manufactured with the injection beam energy upgrading of the LINAC from 181 MeV to 400 MeV. The power supply capacity increases about twice the 181 MeV specifications. The previous SB power supply adapted the IGBT (Insulated Gated Bipolar Transistor) chopping system of the main circuit, which produces the continuous current ripple noise due to the switching [5]. However, the ripple noise on the output current had been resonated with the RF shield loop on the ceramics duct in the SB-magnet, resulting in a forced beam oscillation at the injection stage [4]. The circuit configuration of the new power supply has been changed to the capacitor commutation method using the charging and discharging circuits. This system forms the trapezoid waveform pattern (bump waveform) at 25 Hz repetition with only three times switching per pulse. Therefore, the current ripple noise caused by the switching was reduced considerably.

The SB power supply is comprised of the 16 banks in parallel. The 1 bank includes 12 rise-fall units (Rf-unit) and 2 flat-top units (Ft-unit), which produces an output current of 2 kA and an output voltage of 12 kV. So the maximum output current and output voltage are 32 kA and 12 kV, respectively. By controlling the capacitor voltage and the gate timing of the changeover switch in each unit individually, the power supply can produce an arbitrary waveform which has different rise-fall time and flat-top time duration with high accuracy. The RCS provides a high intensity beam for the MLF (Material and

Life Science Experimental Facility) and MR (50-GeV Main Ring) in a time-sharing mode. The bump system changes the output current to meet the demand of different painting areas for the MLF and MR beams [6]. This paper summarizes the design and the experimental results of the new power supply.

## OVER VIEW OF THE POWER SUPPLY

### Basic Circuit

The power supply is comprised of two kinds of unit. One is the Rf-unit that produces the peak voltage controlling the rise-fall time of the bump waveform. Another is the Ft-unit that maintains the flatness and duration at the flat-top. The basic circuit of the two units is the same, whose schematic view is shown in Fig. 1. The DC charger charges the main electrolytic capacitor C and the switching device of the IGBT defines each operation mode, which is the powering, regeneration and free-wheeling. The model of the bump waveform and the relationship between each unit and each operation mode are shown in Fig. 2 and Table 1. The peak current is determined by setting each DC charger parameter for the charging voltage of the capacitor and the duration of the rise-fall and flat-top is determined by the switching in a predetermined timing of each operation mode.

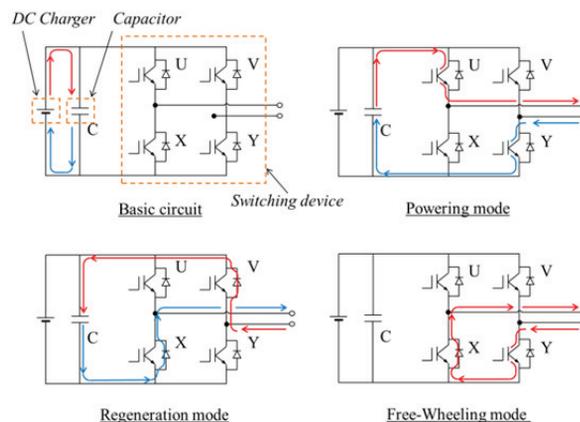


Figure 1: Base circuit of the unit.

### Power Supply Construction

The schematic view of the 1 bank is shown in Fig. 3. The 1 bank is comprised of 12 Rf-units and 2 Ft-units, where all units are connected in series with the midpoint earth. The Rf-unit has two chopper stages connected in series. The capacitor unit is composed by 8 capacitors of 24 mF and the composite capacitance is 48 mF per one DC charger. The Ft-unit has two chopper stages with different charging voltages in order to change the output

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current alternatively in a time-sharing mode. The composite capacitance can be varied from 48 mF to 192 mF by changing the parallel-to-serial connections of the 8 capacitors of 24 mF. The corresponding unit at a positive and a negative side is set the same charging voltage.

In the case that the parameter of the output current is changed in a time-sharing mode, the Rf-units from 1 to 4 are set the same charging voltage and the units 5 and 6 are set differently for MR and MLF. Each structure of the Rf-unit and the Ft-unit is the same type. This system provides the easy maintenance so that only the breakdown unit should be changed when the broken unit is generated.

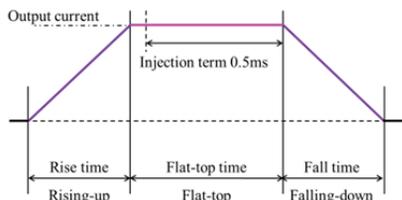


Figure 2: Model of the bump waveform.

Table 1: Relationship Between Each Unit and Mode

Condition	Rise-fall unit	Flat-top unit
Rising-up	Powering	Free-Wheeling
Flat-top	Free-Wheeling	Powering
Falling-down	Regeneration	Free-Wheeling
Off	Regeneration	Free-Wheeling

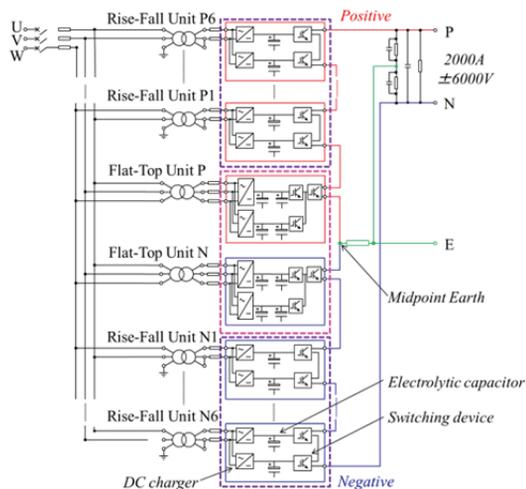


Figure 3: Schematic view of the 1 bank.

## MEASUREMENT RESULT

### Operation Parameter

The new power supply had been operated at the 3-GeV RCS in February, 2014. Low ripple current noise and the high flatness of the bump waveform during the beam injection were confirmed. The measurement result is shown in Fig. 4, which is a typical waveform for the user operation. The output current shows the sum signal of the DCCT outputs of 16 banks. Each output current of the

bank is shown in Fig. 5. The maximum deviation between each output current is about 0.19 kA, which is sufficiently smaller than the total current 22.1 kA. This deviation is produced by the difference of the internal impedance of each bank.

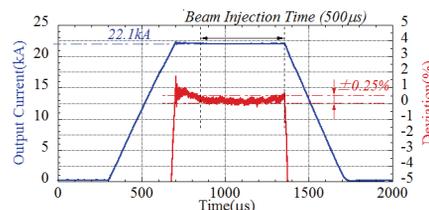


Figure 4: Measurement result of the sum output current. (Charging voltage: P1-4, N1-4, P6, N6=370V, P5, N5=0V, FT-PN=140.0V).

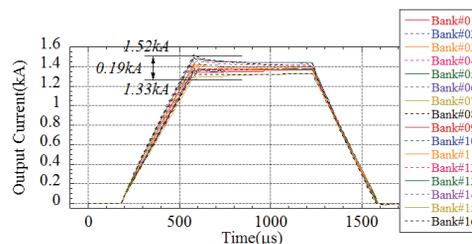


Figure 5: Each output current of 16 banks.

### Reduction of the Surge Voltage

The surge voltage of the output terminal at the power supply can be reduced by shifting the timing of the output from the Rf-unit. The waveform of the output voltage and the timing gate pattern of the switching devices of unit 1 and 3 are shown in Fig. 6. The output timing of both the rising-up and the falling-up of the unit 1 and 3 is shifted by 5 μs from that of other units. The peak voltage decreased by 0.4~0.7 kV. This is effective for overvoltage protection of the magnet.

### Change the Rise-Fall Time of the Bump Waveform

The power supply has the performance that can change the rise-fall time between 150 μs and 500 μs. The measurement result is shown in Fig. 7, which shows the output waveform of 1 bank in the factory with a dummy load. In the actual operation with the RCS, the output voltage with fast rise-fall time causes the breakdown of the RF shield chip capacitor of the magnet. Each peak current and voltage is 1800 A / 12 kV and 2000 A / 5 kV, and each flatness is ±0.18 % and ±0.11 % during the beam injection respectively.

### Deviations in the Output Current by Switching the Flat-Top Parameter in a Time-Sharing Mode

The output current at the flat-top was set 1800 A and 1530 A for MR and MLF, respectively. The pulse sequence is chosen that consecutive 150 pulses are for the MLF and the following 8 pulses for the MR, and so on. Current deviations measured on the first 5 pulses are shown in Fig. 8. The deviation was less than ±0.05 %.

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This measurement was carried out in the factory with a dummy and 1 bank because the switching operation at the flat-top has not been examined so far in the RCS actual operation.

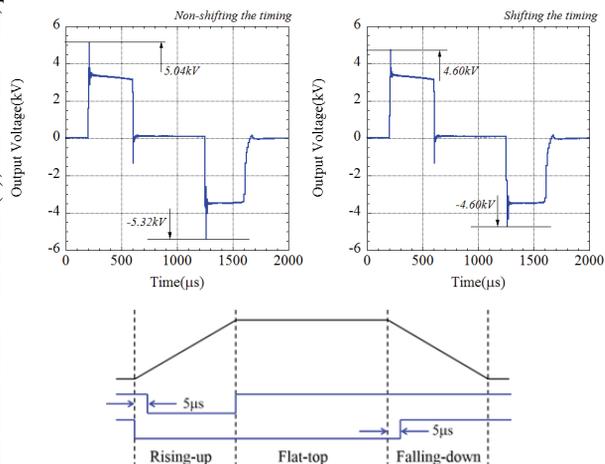


Figure 6: Waveform of the output voltage and the timing gate pattern of the switching device. Shift time is 5µs.

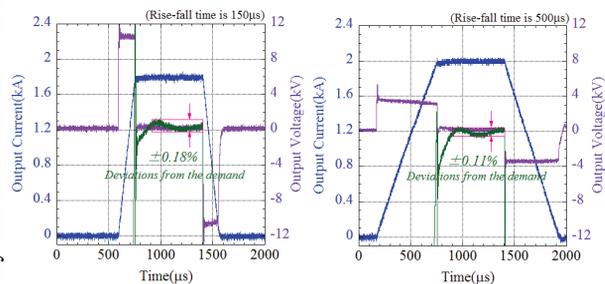


Figure 7: Measurement result of the rise-fall time is 150 µs and 500 µs. (Charging voltage: 150µs: P1-4, N1-4=1152.0V, P5, N5=0V, P6, N6=1100V, FT-PN=133.0V. 500µs: P1-4, N1-4=394.0V, P5, N5=303.0V, P6, N6=0V, FT-PN=143.0V).

### Efficacy of the Composite Capacitance Upon the Flatness

By changing the composite capacitance of the Ft-unit, the difference of the flatness was measured. The result is shown in Fig. 9 for 48 mF and 192 mF capacitance. Current deviations differed by about twice. This test was measured in the factory with a dummy load. In the RCS, the power supply is operated only with 192 mF.

### CONCLUSION

The new power supply for the SB magnet has been developed and manufactured. This power supply newly adapted the capacitor commutation method using the charging and discharging circuit and then low ripple current noise and the high flatness of the bump waveform during the beam injection were confirmed. The driving force to excite the resonant current in the RF shield loop was then reduced. The power supply can produce a trapezoidal waveform in an arbitrary shape with high

accuracy by controlling the charging voltage of the capacitor.

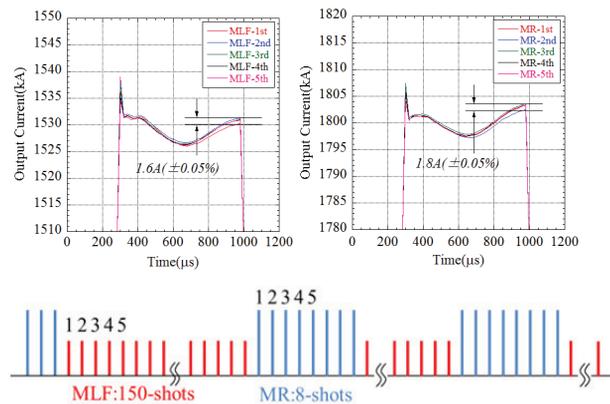


Figure 8: Measurement result of the current deviations.

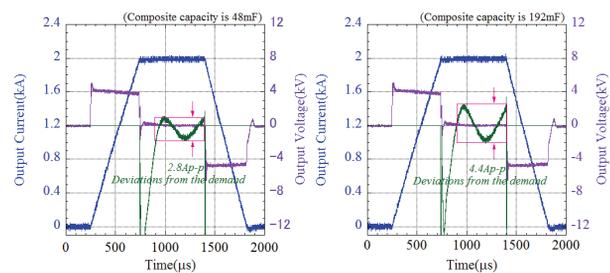


Figure 9: Measurement result of the flatness with differential composite capacitance.

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