UPGRADE DESIGN OF THE BUMP SYSTEM IN THE J-PARC 3-GeV RCS

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Abstract

In the bump system [1, 2] of the J-PARC (Japan Proton Accelerator Research Complex) 3-GeV RCS (Rapid Cycling Synchrotron) [3, 4], the performance improvement according to upgrade of the LINAC (Linear Accelerator) to 400 MeV beam is planned [5]. Both the increase of the power supply capacity and the improvement of the setting accuracy of the output current are required. Moreover, the operating point that the vibration of the current ripple resonates with betatron tune was measured [6]. Therefore, the present level of the current ripple is necessary to decrease to half or less. The development of the pulse power supply system that solves the problems of the current ripple is required. The contents both the improvement plane of the bump system performance and the upgrade system of the power supply are explained.

INTRODUCTION

The J-PARC accelerator consists of the LINAC, RCS and MR (50-GeV Main Ring) [3, 4]. The RCS produces a high intensity beam for the MR and the experimental faculties [4]. In the 1st stage, the beam energy of the injection beam from the LINAC and the extraction beam to MR and MLF (Material and Life science Experimental Facility) is 181 MeV and 3 GeV, respectively. The limit of the extraction beam power is 0.6 MW. In the 2nd stage, the injection beam energy and the beam power are to be upgraded to 400 MeV and 1 MW, respectively [7].

The power supply of the bump system needs to upgrade the performance according the LINAC to 400 MeV injection beam energy. The bump system is composed of the shift bump-magnets (SB), the horizontal paint bump-magnets (PBH) and the vertical paint bump-magnets (PBV). The power supply of the SB increases the output current from 20 kA to 32 kA. Furthermore, the power supply system will be changed to the commutation system of the capacitor with an electrical charge and a discharge, which decreases the switching noises and the ripple current. Each power supply circuit of the paint bump-magnets (PBH and PBV) has been composed of the IGBT (Insulated Gate Bipolar Transistor) assemblies. The controlled switching frequency of the PBH is 600 kHz. The power supplies produce the painting injection trajectory with good accuracy whose deviation to a programmed pattern becomes to be less than ± 0.2 %.

OVERVIEW OF THE BUMP SYSTEM

Bump System of the 3-GeV RCS

The SB produces a fixed main bump orbit to merge the injection beam from the LINAC into the circulating beam of the RCS. They are realized with four magnets connected in series, which are located at the long straight section. The exciting waveform of the SB power supply is as shown in figure 1.

The PBH deflects the circulating beam for the horizontal direction by utilizing the decay waveform with the square root functions during the injection time (500 μs), as shown in Figure 2. They consist of four magnets, which are divided into two pairs. One pair is arranged for the upstream of the F quadruple magnets, and another pair is arranged on the downstream of the D quadruple magnets. Each magnet is excited individually.

The PBV named to vary the injection angle and the position vertically for painting the injection beam at the first charge-exchanging foil position. They are placed in the transport line at a betatron phase of π upstream of the stripping foil.

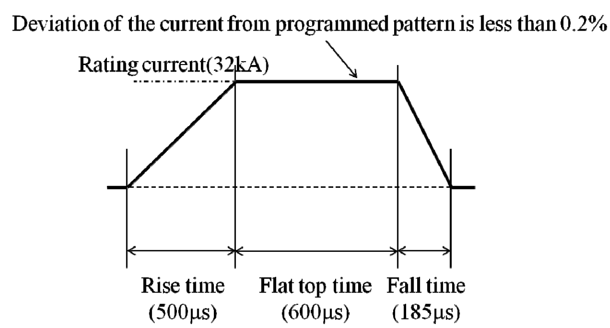

Figure 1: Exciting waveform of the SB power supply.

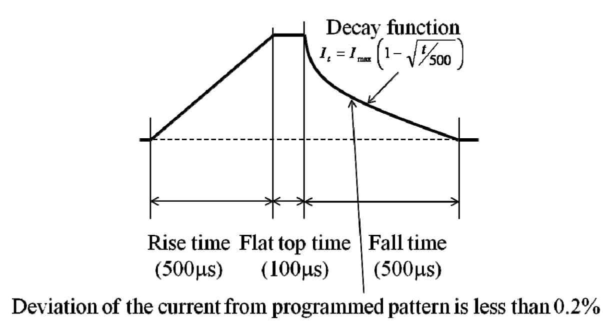

Figure 2: Exciting waveform of the decay function of the PBH and the PBV power supply.

Painting Injection

The painting injection in the transverse plane is executed with the bump system. The painting injection controls the uniformity and the shape of the beam profile.

The injection beam with a small emittance from the LINAC (4 π.mm.mrad) is uniformly distributed to the circulating beam. So the large beam of the high intensity

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that the design of the painting injection areas to the MLF beam and the MR beam are 216 π.mm.mrad and 144 π.mm.mrad respectively is produced.

REQUIREMENTS FOR BUMP SYSTEM

In the 2nd stage, the upgrade plane of the LINAC beam energy to 400 MeV was started in March 2009. This plan will be completed in 2013. Consequently, the 3-GeV RCS will aim at 1 MW beam power.

Each power supply capacity of the bump system is required about 1.6 times rated current and about twice output voltage. Each specification is as shown in Table 1. Furthermore, in order to reduce unnecessary beam loss, which requires the stabilization of the injection beam trajectory realized output current deviation below ± 0.2 %. In addition, high-intensity beam test in the previous commissioning, the second harmonic vibration of a 48 kHz ripple currents on the SB excitation current waveform, and there is the problem that the betatron tune resonance (about 100 kHz) [6] .

In the injection beam energy of 400 MeV, the generating the high intensity beam of 1 MW is the primary goal. To do so, to reduce the unnecessary beam loss is an important issue. Therefore, in high-intensity beam tests, as they have not been limited range of operating points of the betatron tune and the performance of the current deviation apart, we need to solve the problem of the ripple current.

Table 1: Specifications of each power supply of the bump-magnets

Power Supply	181MeV Current／Voltage (kA/kV)	400MeV Current／Voltage (kA/kV)
Shift bump	20.0/6.4	32.0/12.8
H-Paint bump1	17.6/0.8	29.0/1.2
H-Paint bump2	14.2/0.6	23.4/1.2
H-Paint bump3	12.5/0.6	21.0/1.2
H-Paint bump4	12.5/0.6	21.0/1.2
V-Paint bump1	2.05/0.6	3.40/0.6
V-Paint bump2	±1.52/±0.6	±2.5/±0.6

PROBLEM OF THE POWER SUPPLY OF THE SHIFT BUMP-MAGNET

All power supply of the bump system in current design, the main circuits have been composed by the multiplexing circuit of IGBT assemblies. Thus, it becomes possible to output the arbitrary waveform pattern. However, the current ripples on the exciting waveform have been occurred due to the chopper with high frequency switching. The shift bump power supply is composed by 8 multiplexing circuit of IGBT assemblies. The carrier frequency of the IGBT choppers is 6 kHz and the controlled switching frequency is 48 kHz. The fundamental harmonic of the frequency is generated in the excitation waveform.

The deviation of the output current is evaluated including the minutes of the ripple current amplitude. The SB power supply that the rating current is 20 kA, the current amplitude of 200 A from the specification of ± 1.0 % or less have been acceptable. However, this current amplitude has caused the resonance of the betatron tune. So the beam loss has been increased at the acceleration process. Therefore, the power supply upgrade of the SB is required that the ripple current to zero as possible.

The power supply capacity of the SB for the upgrade, the rating current is 32 kA and the output voltage is 12.8 kV. When designing a system composed of the IGBT chopper circuit similar to the current power system to satisfy this specification, the multiplexing circuit of IGBT assemblies is composed by 16 series and 11 parallels. The carrier frequency of the IGBT choppers is 6 kHz and the controlled switching frequency of 16 multiple assemblies is 96 kHz. So the amplitude of the ripple current due to the chopping, the calculation is halved. However, because the fundamental frequency is resonated, the problem of the resonance is not resolved.

As a countermeasure, the changing of the carrier frequency of the IGBT chopper has been considered. In the preliminary tests, the carrier frequency of the IGBT chopper is changed from 6 kHz to 4 kHz. In the results of the frequency analysis of the measured wave excitation, the fundamental frequency has been shifted from 48 kHz to 32 kHz, as shown in figure 3. In the case of the carrier frequency change to 8 kHz, the controlled switching frequency of 16 multiple assemblies is 128 kHz, the resonance point can be shifted. Furthermore, the current ripple amplitude will be reduced to approximately 38 % of 200 A. However, the speed of the carrier frequency of the IGBT device to be fast, the heat load becomes an issue of the device measures. Also, if you make the power supply of the chopper circuit of the 176 assemblies, the high frequency noise by increasing the number of IGBT devices is increased.

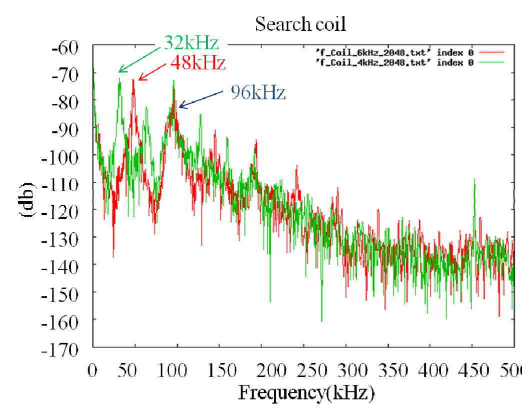

Figure 3: Result of the frequency analysis of the exciting magnetic field using the search coil placed inside the SB.

MAIN CIRCUIT OF THE POWER SUPPLY

New Design of the Shift Bump Power Supply

The power supply for the SB is planned to use the commutation system of the capacitor with an electrical charge and a discharge. This system is composed by many capacitor banks that composed of two kinds units. Figure 4 shows the schematic of the basic circuit of one bank. Each capacitor bank composed by the starting-up and the falling-down units (up-down units) and the flat-top units. Each unit is connected in series and the waveform pattern at a trapezoidal shape has been created by the 3 switching timing of the units. The switching number of the noise sources will reduce. Moreover, the current ripple does not occur in principle due to the chopper. Therefore, we can minimize the high frequency leakage noise and solve the betatron tune resonance.

However, no actual production of high current and high voltage power supply specifications corresponding to the SB with this system. In addition, to use many capacitors in the limited space, the capacitors with a small size and a high capacitance need to develop.

Paint Bump Power Supply

The circuit of the IGBT choppers is two-quadrants and each assembly is consisted of 1200V-300A IGBT element. It is composed of a lot of parallel numbers corresponding to the current rating of each power supply. The schematic diagram of the main circuit of the horizontal paint bump-magnet of 1 is as shown in figure 5. The main circuit of the IGBT choppers is considered as 6 multiple-connections. The same carrier wave is used for every three parallels, and so the phase of the carrier wave is shifted on the plus current side C and the minus current side D. The circuit composition as a whole becomes 12 multiples. The carrier frequency of the IGBT is 50 kHz and so the controlled switching frequency becomes 600 kHz. The power supply composed the IGBT assembly have capable to produce the arbitrary waveform at the controlled time in 500 μs. The high frequency switching of the IGBT choppers executes the good accuracy less than ± 0.2 % deviation to programmed pattern.

SUMMARY

To determine the power supply circuit of the SB, it is necessary to examine and clarify the advantages and disadvantages of each system that the IGBT chopper and the commutation capacitors. R & D unit of the commutation capacitor is produced. The results will be evaluated in comparison with the chopper type power supply test results that are currently running.

As for the paint bump-magnets power supply each horizontal and vertical, it needs to be output the any waveform shape for painting injection. So the IGBT chopper system is used.

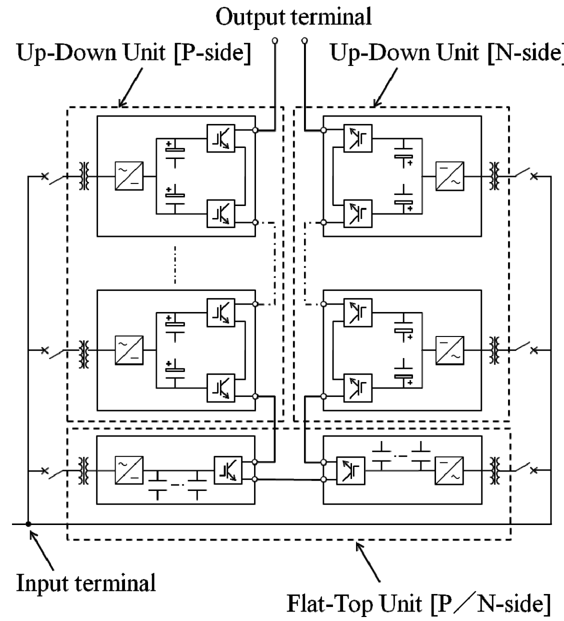

Figure 4: Schematic diagram of the main circuit of the SB power supply used the commutation system of the capacitor bank.

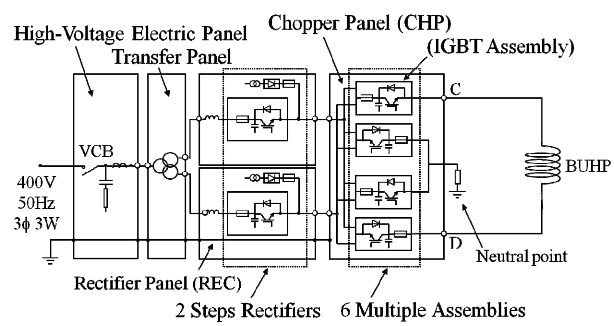

Figure 5: Schematic diagram of the main circuit of the PBH power supply whose are 6 multiple-connections of the IGBT assemblies.

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