MEASUREMENT RESULTS OF THE CHARACTERISTIC OF THE PULSE POWER SUPPLY FOR THE INJECTION BUMP SYSTEM IN J-PARC 3-GEV RCS

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Abstract

The main circuit of the pulse power supplies for the injection bump system [1] of the 3-GeV RCS (Rapid Cycling Synchrotron) in J-PARC (Japan Proton Accelerator Research Complex) [2] [3] is composed of multiple-connections of the Insulated Gate Bipolar Transistor (IGBT) assemblies. The element of the IGBT assembly, which is the power supply of the shift bump-magnets, is a type of 3300V-1200A and 6 kHz in elementary frequency. The synthetic frequency of the multiple-connection of the assemblies is over 48 kHz. Another IGBT assembly of the paint bump-magnet has a type of 1200V-600A and 50 kHz in elementary frequency. The synthetic frequency is more than 600 kHz. It is the possible that the flexible decay waveform with the square root function during the 500 μs of the injection time is can be generated.

The long-term operation of the power supply was performed. The deviation of the exciting current from the programmed pattern was confirmed less than 1 % for about two-week.

The peculiar characteristic of the pulse power supply with the IGBT assemblies has been obtained by the analysis on the frequency of the exciting current and the magnetic field. In the Fast Fourier Transformation (FFT) analytical results of the magnetic field, the peaks of 48 kHz, 600 kHz and their higher harmonics were observed.

INTRODUCTION

The J-PARC accelerator consists of 181 MeV Linac, 3-GeV RCS, and 50-GeV synchrotron (MR). The proton beam from the Linac at 181 MeV has been successfully injected into the RCS and circulated on October 26th in 2008. Furthermore, the acceleration up to the design energy at 3 GeV and the extraction to the beam dump has been achieved on October 31st.

The injection bump system of the RCS is composed of the shift bump-magnets, the horizontal paint bump-magnets and the vertical paint magnets [4] [5]. The shift bump-magnets produce a fixed main bump orbit to merge the injection beam from the LINAC to the circulating beam of the RCS. The horizontal paint bump-magnets produce the trajectory for the painting injection and the vertical paint magnets control the injection angle of the injection beam for the vertical at the first charge-exchanging foil position.

To produce the fixed bump orbit and the painting injection trajectory with good accuracy, each power supply is required the accuracy whose deviation to a programmed pattern becomes to be less than 1 %. Furthermore, to produce the flexible decay waveform of the square root function, the tracking error to be less than 1 % for 1 μs pulse current is required. To realize the performance, the pulse power supply composed by the IGBT assemblies with a high frequency was produced.

The painting injection system of the RCS is designed to facilitate painting in both correlated and anti-correlated painting injections. They are achieved by changing the excitation pattern of the vertical paint magnet power supply.

COMPOSITION OF THE MAIN CIRCUIT OF THE PULSE POWER SUPPLY

Shift Bump Power Supply

The power supply of the shift bump-magnet is composed by multiple-connection of the IGBT assemblies. The circuit is shown in Fig. 1. The composition of the rectifier panel (REC) is four steps. The chopper panel (CHP) is eight multiple assemblies and seven parallels are adopted. The number of the total assemblies is sixty. The elementary frequency of the IGBT choppers is 6 kHz and the controlled switching frequency of eight multiple assemblies is 48 kHz. The IGBT element is a type of 3300V-1200A. Each assembly has three parallel IGBT choppers with two-quadrants and the parallel number of the IGBT choppers is twenty-one. So the output voltage and the current is controlled by 6600 V and 20 kA.

Paint Bump Power Supply

The circuit of the IGBT choppers is two-quadrants and each assembly is consisted of a 1200V-300A IGBT element. The whole of the circuit, each assembly is composed in eighteen parallels. Because the same carrier wave is used for every three parallels, the main circuit of the IGBT choppers is considered as six multiple-connections. The phase of the carrier wave is shifted on the plus current side C and the minus current side D, and so that becomes twelve multiples as a whole. The elementary frequency of the IGBT switching is 50 kHz and the synthetic frequency becomes 600 kHz. The simulation as the condition of the exciting current is 17.6 kA and controlled time is 500 μs shows the tracking error less than 0.59 %.

The power supply composed the IGBT assembly has capable to produce the arbitrary waveform. The high

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frequency switching of the IGBT choppers executes the good accuracy less than 1 % deviation to programmed pattern because of the tracking error less than 1 %.

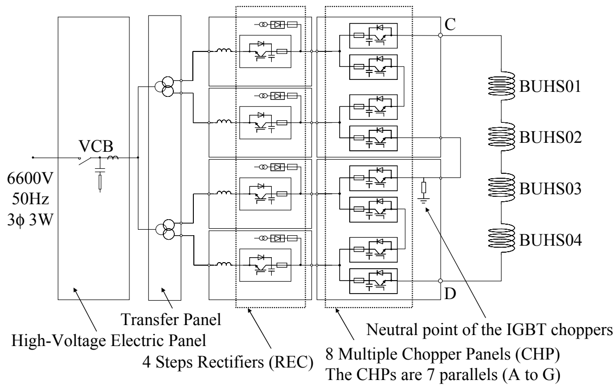

Figure 1: Schematic view of the main circuit of the shift bump power supply.

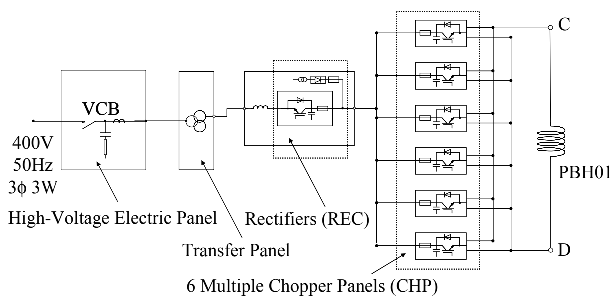

Figure 2: Schematic view of the main circuit of the paint bump power supply.

LONG-TERM OPERATION

A long-term operation of the shift bump power supply was performed. Each deviation of the exciting current from the programmed pattern and the magnetic field with long search coil setting in the magnetic core was measured. Furthermore, the temperatures of the IGBT CHP board, the cooling waters of the CHP and the magnet and so the room temperature of the power supply arrangement area were measured at the same time. Fig. 3 and 4 show each result. The operation parameter of the power supply was a repetition frequency of 25 Hz and the trapezoid waveform whose flattop current is 13.4 kA. It is equivalents to a center injection condition. The risetime, flattop time and the falling time of the trapezoid waveform are 500 μs, 220 μs and 500 μs, respectively.

The deviation of each current and magnetic field has been confirmed less than 1 % for about two-weeks. Especially, a critical influence was not observed in the measurement result in spite of a temporary stop of the power supply and a rapid change in the temperature of the cooling water.

ARBITRARY WAVEFORM

In order to measure a closed orbit distortion (COD) due to the imbalance of the four paint bump-magnets, the current pattern of the trapezoid waveform was performed [6], as shown in Fig. 5. The deviation of the exciting current from the programmed pattern was confirmed less than 1 % at the flat top time. The setting parameter of each power supply is the painting injection of 150 π.mm.rad.

For the painting injection, the decay waveform of the horizontal paint bump-magnet and the vertical paint magnet is required. Furthermore, the injection system is designed to facilitate painting in both correlated and anti-correlated painting injections. They are achieved by changing the excitation pattern of the vertical paint magnet power supply. The decay waveform pattern for the painting injection is basically square root function of the injection time τ (500 μs). Each function follows the following equations, (see Eq. 1 to 3).

$$Horizontal\ Painting = I_{max}\left(1-\sqrt{t/\tau}\right) \qquad (1)$$

$$Correlated\ Painting = I_{max}\left(\sqrt{t/\tau}\right) \qquad (2)$$

$$Anti-Correlated\ Painting = I_{max}\left(\sqrt{1-t/\tau}\right) \qquad (3)$$

Fig. 6 and 7 shows the correlated and the anti-correlated painting injections waveform, respectively. The deviation of the current from the programmed pattern was confirmed less than 1 % during the injection time (500 μs). The setting parameter of each power supply is the painting injection of 100 π.mm.rad.

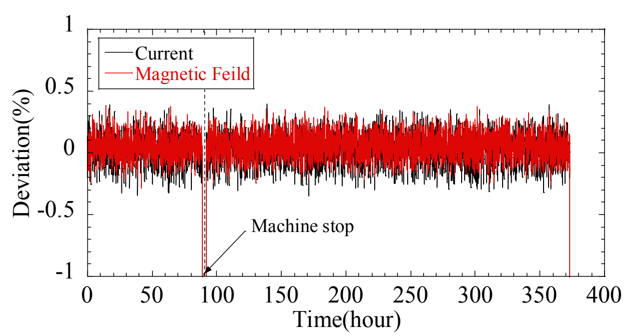

Figure 3: Long-term deviation of the current and the magnetic field for the shift bump system.

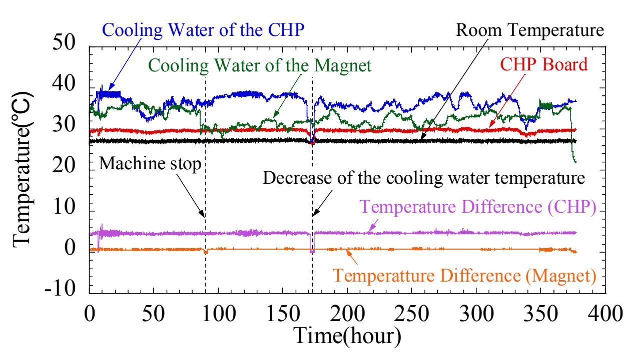

Figure 4: Long-term fluctuation of temperatures at relevant points.

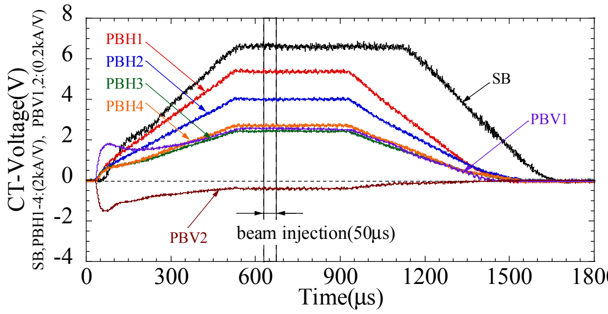

Figure 5: Trapezoid waveform to measure the COD.

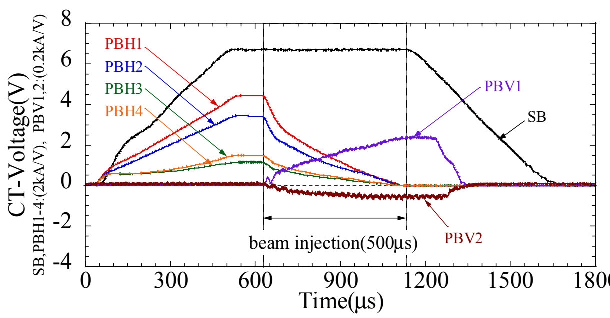

Figure 6: Painting injection waveform with correlated painting.

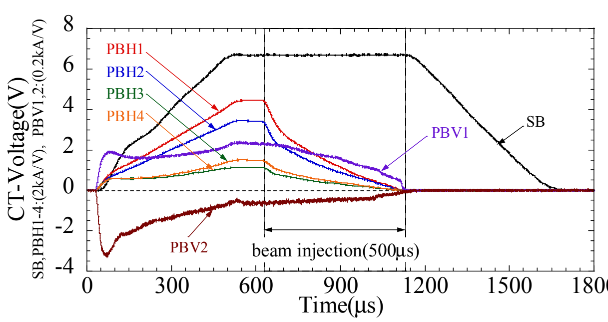

Figure 7: Painting injection waveform with anti-correlated painting.

PECULIAR CHARACTERISTIC OF THE BUMP POWER SUPPLY

The decay waveform of the exciting current pattern is produced by the high frequency switching with IGBT choppers. The influence of the ripple current due to the switching given to the magnetic field was examined. The magnetic field was measured by a long search coil that is 400 mm in length and 6 mm in width, setting on the surface of the magnetic core inside the gap.

The peculiar characteristic of the pulse power supply with the IGBT choppers was obtained by the FFT spectrum of the exciting current and the magnetic field, as shown in Fig. 8 and 9. The sampling time of the FFT is about 5 ms. The exciting current is measured by PEARSON CT (model 1423) and the FFT analysis was executed. Though the cut off frequency of the CT is 1.2 MHz, the higher harmonics of over 50 kHz were not observed. In the FFT analysis of the magnetic field, the peaks were able to be confirmed in the wide range. The peaks of 48 kHz and 600 kHz its higher harmonics that are related to the switching frequency of each power supply, which is the shift bump-magnet and the paint bump-magnet, were observed, respectively.

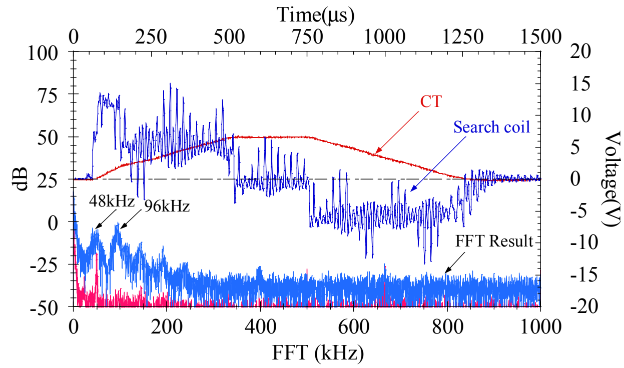

Figure 8: FFT spectrum of the exciting current and the magnetic field of the shift bump-magnet.

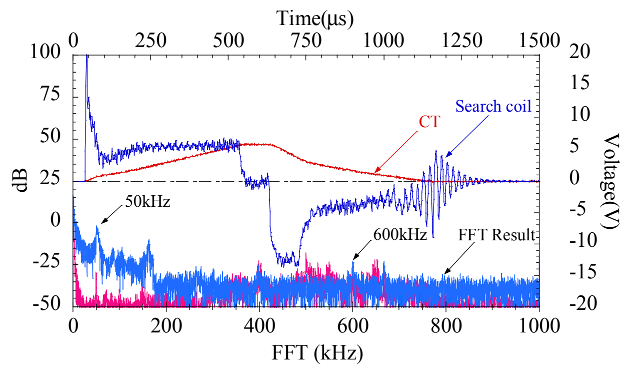

Figure 9: FFT spectrum of the exciting current and the magnetic field of the horizontal paint bump-magnet.

SUMMARY

The trapezoid waveform and the flexible decay waveform required for each beam commissioning and the painting injection [6] have been confirmed. Furthermore, it was confirmed that the stability of the output current satisfied the required accuracy with continuous operation of a long term. The FFT analysis of the magnetic field showed the harmonics components of the IGBT switching frequency. It is in progress to study the influence of the harmonics given to the beam.

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