SUPPRESSION SCHEME OF COD VARIATION CAUSED BY SWITCHING RIPPLE IN J-PARC 3GEV DIPOLE MAGNET POWER SUPPLY

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Abstract

In the J-PARC 3GeV synchrotron, the horizontal closed-orbit-distortion (COD) variation was observed at first of beam commissioning. The COD correction was very difficult to archive because the beam orbit of each shot changes periodically at a period of about 140 seconds. This paper clarifies that the horizontal COD is caused by the switching noise of the dipole magnet power supply and the periodic variation of the beam orbit is caused by the phase sweep of 1kHz component that include switching noise. Moreover, it has been demonstrate that the dipole magnet power supply using the improved Pulse Width Modulation (PWM) circuit with a synchronized timing system of the accelerator has successfully suppressed the beam orbit variation.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton accelerator facility designed to produce at MW-class output beam power. The J-PARC accelerator complex consists of a 181-MeV linac, a 3-GeV rapid cycling synchrotron (RCS), a 50-GeV synchrotron, and several experimental facilities. The 3-GeV RCS accelerates a 181-MeV proton beam from the linac up to 3-GeV at a repetition rate of 25 Hz. In the 3-GeV RCS, the dipole and quadrupole magnets are excited using a resonant network that is known as the "White Circuit." Those current patterns are DC-biased sinusoidal waveform, as shown Fig. 1. Fig. 2 shows the horizontal beam position measured from the beam position monitor during acceleration at the following intervals: 0 s, and then after 50 s, 94 s, and 138 s. The variation of the beam orbit has amplitude of about ±2 mm just after the injection, and the variation is reduced as accelerating. The main component of the beam orbit variation is 1 kHz, the beam orbit of each shot changes periodically at a period of about 140 seconds. This orbit variation appears only horizontally and not vertically, the value of 1 kHz is equal to the switching frequency of the dipole magnet power supply. Therefore, we concluded that the horizontal COD source is caused by the switching noise of the dipole magnet power supply.

CURRENT AND MAGNETIC FIELD MEASURMENT

We measured the magnetic field and current of the dipole magnet using a short coil installed in the center of

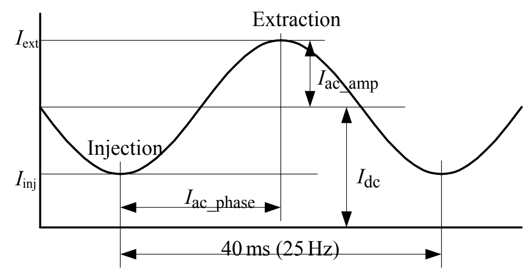

Figure 1: Waveform pattern of the dipole magnet current.

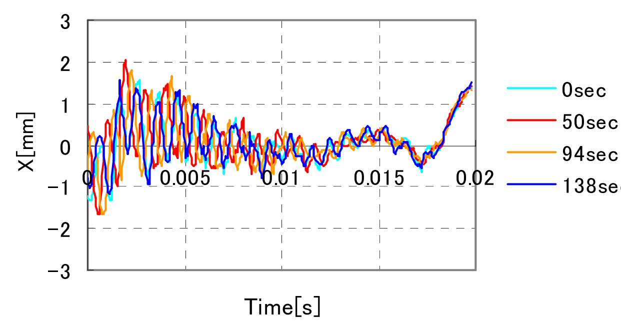

Figure 2: Time variation of horizontal beam position during acceleration.

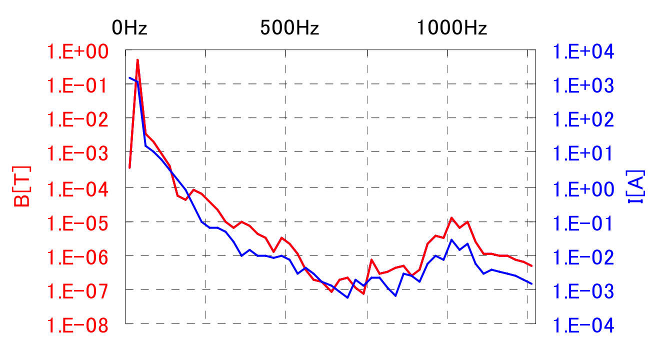

Figure 3: FFT results of the magnetic field (red) and current (blue) in the dipole magnet.

the magnet and HITEC DCCT, respectively. The data acquisition of the current and the magnetic field are 16 bits ADC with 100 kHz of sampling clock. The sampling clock of the ADC divides from the master clock (12 MHz) that is supplied from the timing system of the J-PARC [1]. The FFT results are calculated from the 1 second sampling data, which is 100k byte data. Hence, the frequency resolution of the FFT is 1Hz.

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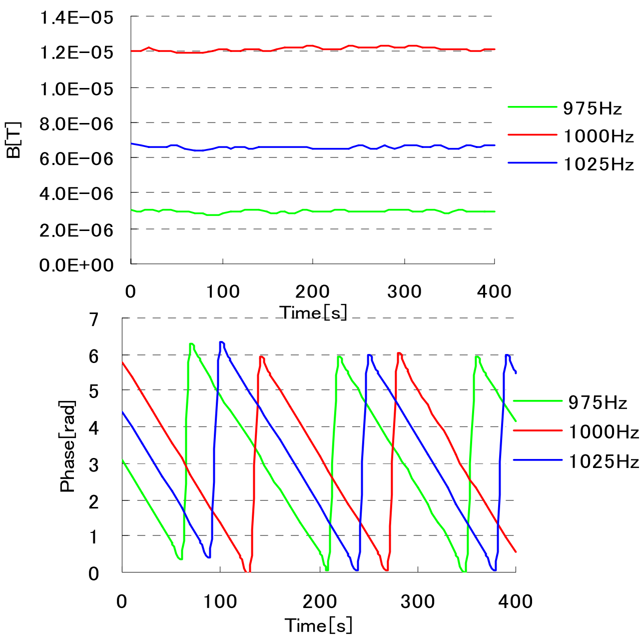

Figure 4: Time variation of around the 1 kHz component in the dipole magnetic field. (Upper: amplitude, Lower: phase)

Fig. 3 shows the FFT results of the magnetic field and current in the dipole magnet. Each FFT results appear at peak around the 1kHz component. In magnetic field, the amplitude of the 1kHz component is 1.2 × 10-5 T, which is 0.067 % of the injection field 0.18 T.

To focus on the time variation of around the 1kHz component, Fig.4 shows 975 Hz, Fig.4 shows 1 kHz, and 1025 Hz components of amplitude and phase of the magnetic field. The amplitude is almost constant, however, the phase is sweeping at a period of about 140 seconds, which is equal to the period of the beam orbit variation. The reason is the switching timing of the dipole magnet power supply that is determined by its inside oscillator; on the other hand, the sampling clock of the data acquisition determined by the accelerator timing system of the J-PARC. Therefore, the results suggest that phase sweeping can be suppressed by the switching timing of the dipole magnet power supply synchronized with the accelerator timing.

DIPOLE MAGNET POWER SUPPLY

Fig. 5 and table 1 show the resonant network of the dipole magnet power supply and its specification, respectively. There are 25 dipole magnets included in one monitor magnet [2]. The resonant network comprised of 25 resonant cells connected in series. One resonant cell, which is tuned for 25 Hz, consists of one magnet, one choke-transformer, and one capacitor bank. The excited power is separated from the AC power supply (ACPS) and the DC power supply (DCPS). The DCPS is connected in series with one resonant unit, and the ACPS is connected with the each primary side of 25 choke-transformers in parallel.

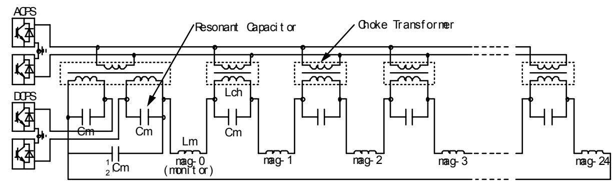

Figure 5: Resonant network of the dipole magnet power supply.

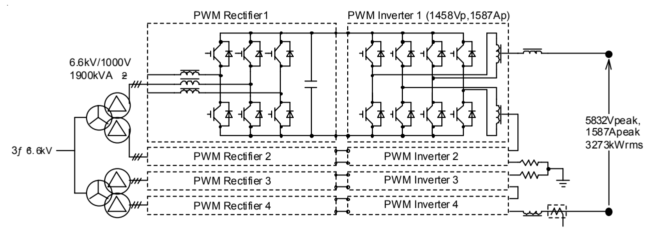

Figure 6: Circuit configuration of the ACPS.

Table 1: Specifications of the dipole magnet power supply

Magnet Inductance : Lm	62.0 mH
Choke Inductance :Lch	62.0 mH
Capacitor : Cm	1227 uF
Injection current	421 A
Extraction current	2666 A
Injection Filed	0.18 T
Extraction Filed	1.15 T
DC power supply	4436 kW
Voltage rating	2661V
Current rating	1667A
AC Power supply	3273 kW
Voltage rating	5832 V
Current rating	1587 A

Fig. 6 shows a circuit configuration of the ACPS. The ACPS is composed of the step-down transformer, four PWM rectifier cells, and four PWM inverter cells. One PWM inverter cell is composed of two H-bridge inverters with a common DC-link capacitor, and the output sides are connected through the inter-phase reactor. The output side of each inverter cell is connected in series. The switching element of the rectifiers and the inverters uses IGBT of 3.3 kV-1.2 kA. The switching frequency of each IGBT is 1kHz and the equivalent switching frequency of the total inverter is 16 kHz, as described in the next section.

IMPROVEMENT OF PWM CIRCUIT

It is necessary to synchronize the switching timing of the power supply and the accelerator timing; the carrier signal of the PWM circuit of the power supply should be generated from the timing system of the accelerator. Fig. 7 shows the PWM circuit of the ACPS. The PWM circuit generates the switching time signal from the voltage reference signal and the carrier signal through the analog comparator. The switching frequency of the each IGBT is 1kHz; hence, the carrier signal is 1kHz.

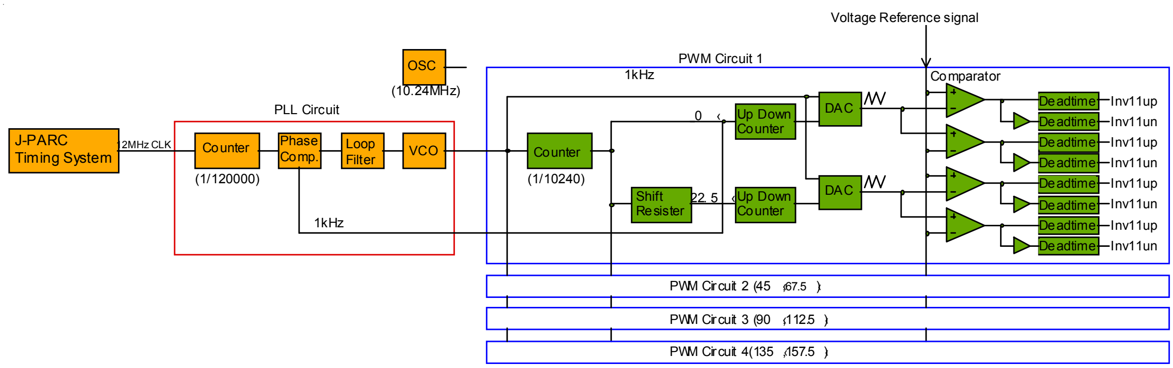

Figure 7: Improved PWM circuit for the dipole magnet power supply.

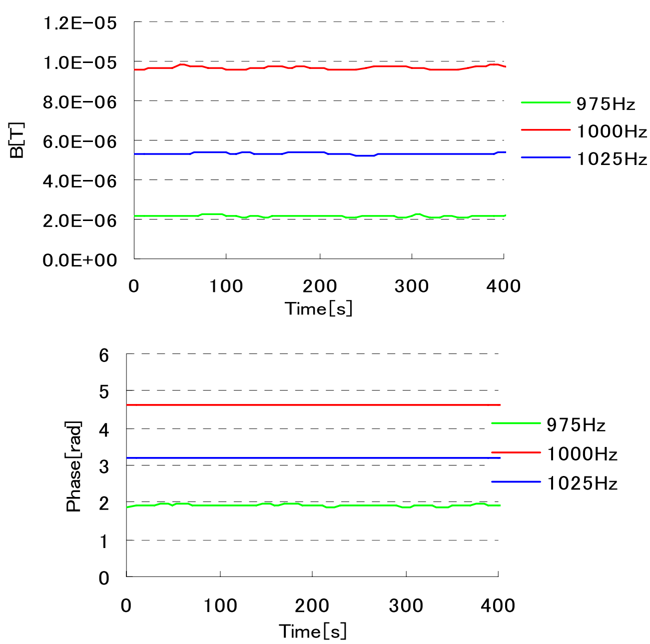

Figure 8: Time variation of around the 1 kHz component in the dipole magnetic field using the improved PWM circuit. (Upper: amplitude, Lower: phase)

To increase the equivalent switching frequency of the ACPS, the phase of the carrier signal of each inverter is IGBT by 22.5 degrees (360 degrees/16). As a result, the equivalent switching frequency of the ACPS is 16 kHz. The carrier signal is generated using the shift register, up/down counter, and 11-bit DAC; each device is synchronized to a common clock. In a conventional PWM circuit, the common clock is generated from its inside oscillator (OSC), which has a frequency of 10.24 MHz. On the other hand, in the improved PWM circuit, the common clock is generated from the accelerator timing system through the PLL circuit. The PLL circuit is composed of the phase comparator, loop filter, and VCO. To decrease the jitter of the carrier signal, the loop filter sets the 1kHz element as low as possible.

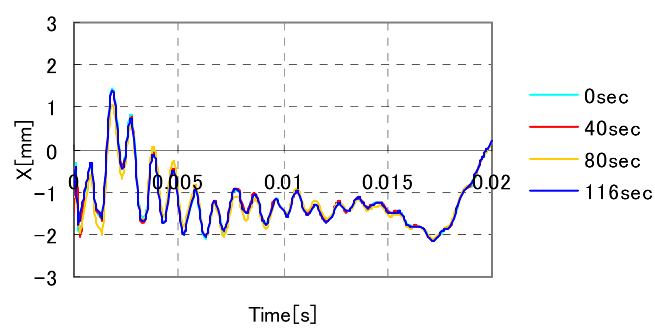

Figure 9: Time variation of horizontal beam position during acceleration using the improved PWM circuit.

TEST AND COMMISIONING

Fig. 8 and 9 show the time variation of the magnetic field around the 1 kHz component and the horizontal beam position during acceleration using the PWM circuit synchronized with accelerator timing, respectively. The phase of the magnetic field is almost constant and the time variation of the beam orbit is suppressed.

SUMMERY

In this paper, a dipole magnet power supply using the improved PWM circuit with a synchronized timing system of the accelerator was used to successfully demonstrate the suppression of the beam orbit variation. The dipole magnet power supply with the improved PWM circuit showed stable operation for a period of one year.

ACKNOWLEGMENT

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