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DESIGN OF FAST CORRECTOR POWER SUPPLY FOR HEPS

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Abstract

High energy photon source is a fourth-generation synchrotron radiation light source with energy of 6Gev and ultra-low emittance (<0.1nm•rad). [1] The ultra-low beam emittance requires high beam stability. Therefore, we develop a fast corrector power supply with high bandwidth and low current ripple to improve the performance of the fast close orbit correction system to prove the high beam stability. The power supply adopts FPGA for full-digital control and use high speed ADC with temperature control. The power supply has a small signal-bandwidth of 10 kHz and output current ripple lower than 20ppm. In this paper, we will describe the hardware design and software control methods and the test results will be demonstrated.

INTRODUCTION

The Chinese high energy synchrotron radiation light source to be constructed soon is a high energy synchrotron radiation light source with an electronic energy of 6 GeV and an emittance less than 0.1nm •rad. [1] A high performance fast track feedback system (FOFB) system is required to meet the strict beam position requirements and keep the beam in the set closed-loop orbit. The fast track feedback system consists of three key components: beam position measurement (BPM), track compensation computing unit and fast magnet correction power supply system. Fast correcting magnet power supply requires 10 kHz bandwidth and the lowest possible output current ripple.

In the paper, the fast corrector power supply adopt switch-mode power supply. In order to achieve 10 kHz small signal bandwidth，The hardware topology of the power supply is different from that of the conventional H bridge circuit. The software is controlled by classical PI and the phase correction is designed carefully. The actual performance of the whole system is simulated in MATLAB software, and a prototype is developed for test. Specific data and curves will be given in this paper.

MODELING AND SIMULATION

Due to the actual physical requirements of HEPS, the requirements of fast corrector power supply are shown in Table 1.

Fast corrector power supply adopt mutli-level topology. Figure 1 shows the schematic of the fast corrector power supply.

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Table 1: Specifications of Fast Corrector Power Supply

Parameters	Value
Maximum output current (A)	15
Magnet inductance (mH)	15mH
Magnet resistance (mR)	80
Stability (@<8h)(ppm)	100
Small signal bandwidth(kHz) （1% max）	10
Large signal bandwidth(Hz)	100
Output current ripple(ppm)	20

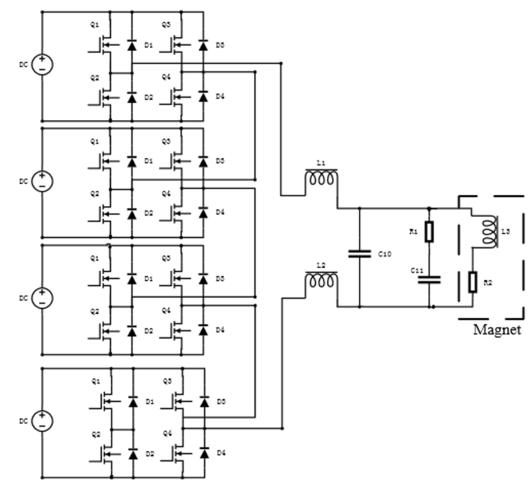

Figure 1: Schematic of power supply.

The power supply adopts the bipolar PWM modulation mode, Fig. 2 shows the system switching mode. The H-bridge PWM control method adopts the carrier phase shift control strategy, the phase shift time T is set as shown in Eq. (1) ,where N is number of H-bridge.

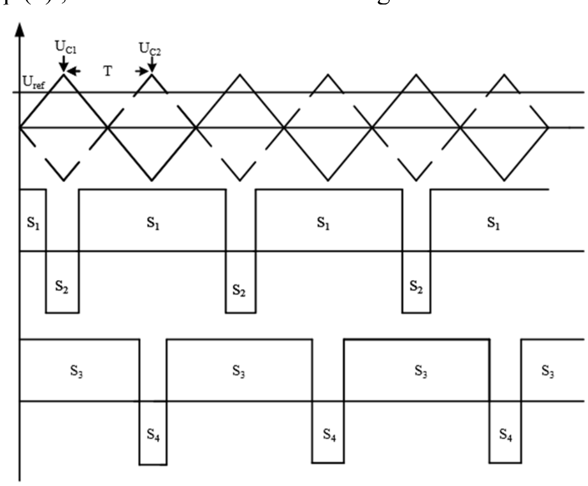

Figure 2: System switching mode.

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$$T = \frac{2\pi}{N}. \quad (1)$$

The load magnet inductance in the whole system has a large time delay, and it is the leading pole that plays an important role in the whole system. Therefore, a phase correction link is actually designed to offset the leading pole and reduce the control effect of this pole. Figure 3 shows the actual phase-correction design.

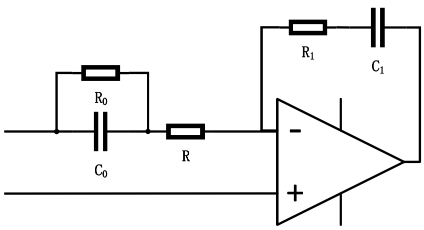


Figure 3: Actual phase-correction design.

The actual transfer function is shown in Eq. (2).

$$Gc(s) = \frac{(s+\omega_1)(s+\omega_2)}{s(s+\omega_3)}. \quad (2)$$

Where $\omega_1 = \dfrac{1}{R_1C_1}, \omega_2 = \dfrac{1}{R_0C_0}, \omega_3 = \dfrac{R + R_0}{RR_0C_0}$

In this design, the poles generated by the load are compensated by the PI loop, and the phase and gain requirements of the system are fulfilled by the phase-lead link. In the practical design, ω_2 should be 10 times greater than ω_1, in order to separate the effects of the PI and phase-lead portions of the compensator. [2]

Using of MATLAB software circuit simulation, Fig. 4 shows the entire simulation environment on MATLAB Simulink.

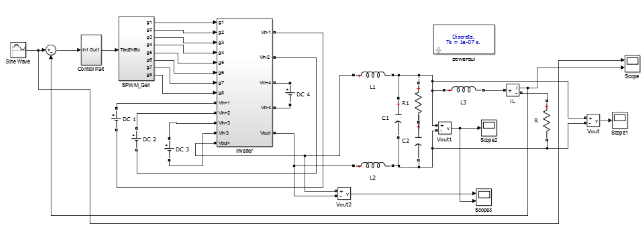


Figure 4: Simulation on MATLAB.

The parameters set for the actual simulation experiment are given in Table 2.

The signals in the control system can be expressed as the synthesis of sinusoidal signals of different frequencies. The Bode graph of the test control system can well represent the frequency response of the system and obtain the dynamic performance of the system. Figure 5 shows the frequency response of the system. The actual results show that the PI controller system with phase correction has 5.75° phase delay and -1.06dB amplitude attenuation at 10 kHz frequency.

System small signal bandwidth test curve is shown by Fig. 6 and simulation results are given in Table 3.

Table 2: Simulation Parameters

Parameters	Value
DC Source(V)	24*4
Output Current (A)	15
Magnet Inductance (mH)	15
Magnet Resistance (mR)	80
PWM Frequency(kHz)	100
Filter Inductance L1&L2(uH)	2
Filter Capacitor (nF)	33
Damping Resistance (Ω)	4.7
Absorption Capacitor(uF)	0.47
Control loop : R0(Ω)	10k
Control loop : C0(uF)	0.13
Control loop : R(Ω)	70k
Control loop : R1(Ω)	571k
Control loop : C1(uF)	0.1

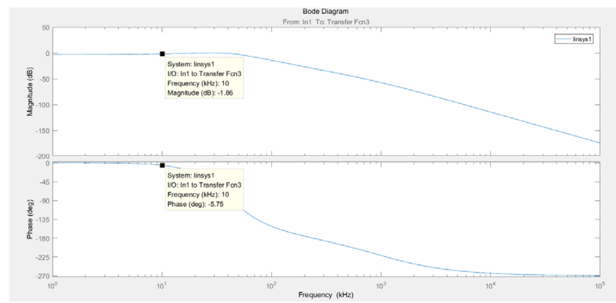
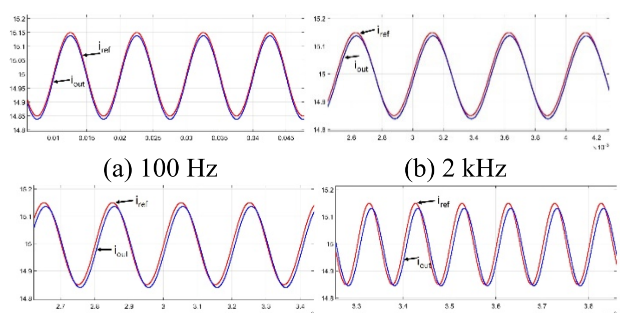


Figure 5: Frequency response.



(a) 100 Hz (b) 2 kHz

(c) 5 kHz (d) 10 kHz

Figure 6: Simulation test curve of bandwidth.

Table 3: Small Signal Bandwidth

Frequency[Hz]	Amp.Atten[dB]	Pha-del [°]
100	-0.007	0.58
2k	-0.007	9.14
5k	-0.009	11.7
10k	-0.01	22.6

PROTOTYPE TEST

A prototype of fast correction power supply is built in practice. The control part is controlled by self-developed digital controller and ADC board with temperature control. Figure 7 shows the actual prototype of fast corrector power supply.

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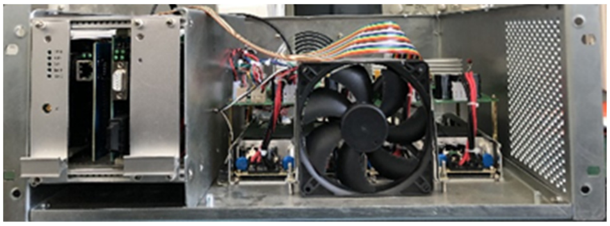


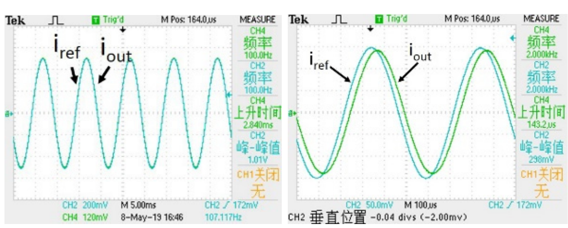
Figure 7: The prototype of power supply.

The actual prototype power supply was used to test the bandwidth performance and output current ripple. The parameters set for the actual prototype experiment are as shown in Table 4.

Table 4: Experimental Circuit Parameters

Parameters	Value
DC source(V)	24*4
Output current (A)	15
Magnet inductance (mH)	15
Magnet resistance (mR)	700
PWM Frequency(kHz)	100
Filter inductance L1&L2(uH)	2
Filter capacitor (nF)	33
Damping resistance (Ω)	4.7
Absorption capacitor(uF)	0.47
Control loop : R0(Ω)	10k
Control loop : C0(uF)	0.13
Control loop : R(Ω)	70k
Control loop : R1(Ω)	571k
Control loop : C1(uF)	0.1

The digital oscilloscope (Tektronix TPS2024B) is used to measure the system bandwidth and the probe is AC coupled. The actual bandwidth test curve of the power supply prototype is shown in the Fig. 8 and the experimental results of bandwidth test are shown in the Table 5.



(a) 100 Hz (b) 2 kHz

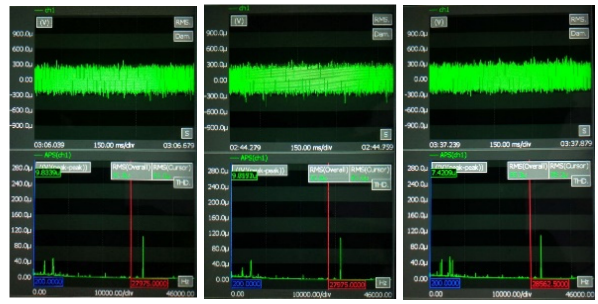
(c) 5 kHz (d) 10 kHz

Figure 8: Test curve of bandwidth.

The dynamic analyser (CRYSTAL CoCo-80X) is used to measure the output current ripple and the probe is AC coupled. The actual current ripple test curve of the power supply prototype is shown in Fig. 9 and the experimental results of current ripple test are shown in the Table 6.

Table 5: Small Signal Bandwidth

Frequency[Hz]	Amp.Atten[dB]	Pha-del [°]
100	-0.17	11.5
2k	-1.41	14.4
5k	-2.15	45.2
10k	-2.81	68.1



(a) 1A DC (b) 6A DC (c) 12A DC

Figure 9: Test curve of output current ripple.

Table 6: Current Ripple

Iout[A]	Ripple RMS(uV)	ppm
1	91.8	18.36
6	94.6	18.92
12	95.3	19.06

CONCLUSION

After testing, the performance of the developed fast corrector power supply prototype meets the design requirements, with the main characteristics of 10 kHz small signal bandwidth, the overall structure of the power supply is simple, the power supply output current ripple is lower than 20 ppm, which can be well applied in the high-energy synchrotron radiation light source engineering.

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