STATUS OF THE FABRICATION OF PAL-XFEL MAGNET POWER SUPPLIES*

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Abstract

The PAL-XFEL has been constructing including a 10 GeV linac, hard X-ray and soft X-ray beam lines. The PAL-XFEL required for about six hundreds of magnet power supply (MPS). The nine different prototypes of MPS are developing to confirm the performance, functions, size, heat load and so on. This paper describes the test results of the prototype MPS in major specifications. All MPSs have to be installed until the end of September in 2015. The installation progress of the MPS was also described.

INTRODUCTION

The PAL-XFEL accelerator needs many kinds of power supplies for different magnet types. Table 1 shows the specifications of the power supplies needed for the PAL-XFEL.

The MPS for corrector magnets are divided into 4 families based on the current rating and stability, 10 A 10 ppm, 10 A 50 ppm , 12 A 10 ppm and 12A 50 ppm.

The MPSs for the dipole and quadrupole were categorized into two types, unipolar and bipolar. And it was grouped to five types according to its current ratings.

Table 1: MPS Specifications

Magnet	MPS type	Qty	Stability (ppm)
Corrector	Digital	395	10 & 50
Quadrupole	Unipolar	122	100
	Bipolar	86	
Dipole	Unipolar	20	20
	Bipolar	2	
Solenoid	Bipolar	3	20

BASIC STRUCTURE

The configuration of the designed MPS was similar with others [1]. The input stage consisted of transformer, full rectifier and a damped low pass filter. The commercial switching mode power supply (SMPS) was often adopted for low power less than 400 W instead. Transformer connection was one of delta or wye windings or sometimes both of them where high stability was required. The low pass filter at the input stage should be needed. Figure 1 shows the general hardware configuration of the MPS.

The topology of the power convertor was either buck for unipolar or H- or half-bridge for bipolar. The output stage was composed of a low pass filter to reduce the switching noise. The output filter composed of two stage LC filters where the pole of the first stage was about ~KHz and second one was between higher than one-half and full of the switching frequency.

The DSP TMS320F28335 from TI Co was used to control the duty of the PWM and to interface surrounding peripherals. It has six enhanced PWM modules with 150 ps micro edge positioning (MEP) technology [2]. Thus effective PWM resolutions can be increased up to about 18-bit in case of switching frequency of 25 KHz. Without MEP, the normal PWM resolution is about 12-bit, which can't offer the sufficient resolution for the high stability.

The power supply performs the Ethernet communication by the single chip WEB server. The WEB server exchanges all power supply data via RS232 connection with the FPGA.

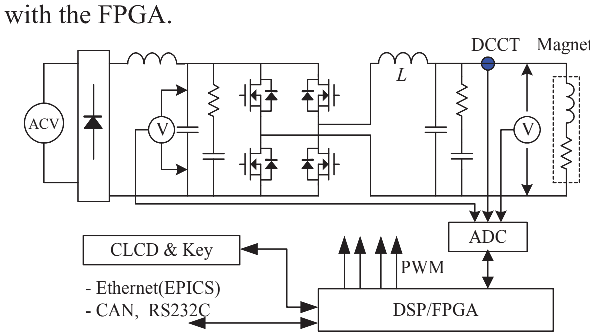

Figure 1: Block diagram of the buck type magnet power supply.

CONTROL SCHEME

The control loops for the developed MPS are given in Fig. 2. A cascaded current and voltage feedback loop was applied to the MPS compensator [3]. The inner voltage loop worked to reject the voltage fluctuation of the output stage. The voltage loop has a small time constant comparing to outer current loop. Thus it can be shown as constant by the outer loop.

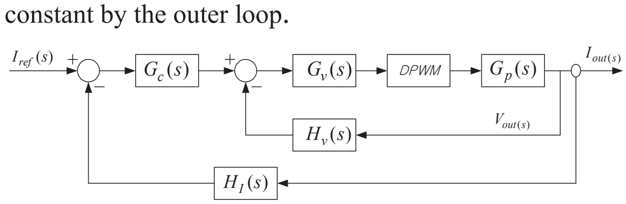

Figure 2: Block diagram of complete current loop system.

The current and voltage compensators were applied a proportional-integral (PI) type which was very common

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in feedback systems. The coefficients of the current loop were 60 for proportional gain and 30000 for integral gain, respectively. Figure 3 showed the frequency and phase responses of the discrete PI compensator when the time period of the loop was 40 µs. The pole located at 0 and zero at the about 80 Hz.

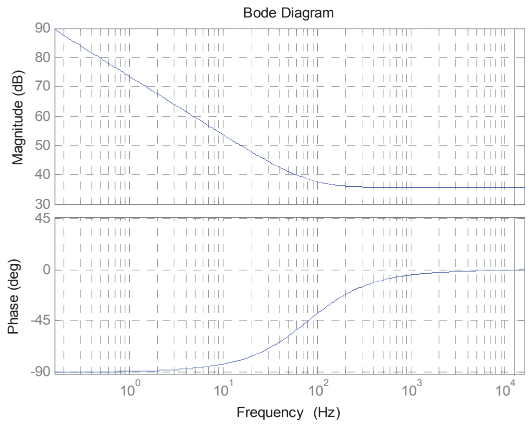

Figure 3: Bode plot of the discrete current PI compensator of the MPS.

PROTOTYPE POWER SUPPLY

All measurement system is consists of three part – HP3458A digital voltmeter from Agilent Co. with external DCCT MACC150 from HITEC, computer and load magnet. Two prototype power supplies are fabricated for verifying performance. The supplies underwent extensive testing at the factory. Testing included verifying the digital interlocks and running each unit for eight hours. The major specifications of MPS were examined about short term stability, step responses at the rising and falling times, zero cross response and long term stability.

Corrector MPS

The prototype MPSs for corrctor magnets were developed . The major specifications are given in Table 2. The total number of corrctor MPS is 432. The four MPSs were assembled into shelf of which height is 3 U. Figure 4 shows the 4 type corrector MPS for prototype.

Table 2: Corrector MPS Specifications

MPS Type	I [A]	V[V]	Qty[ea]	Stability[ppm]
C1	5	12	262	50
C2	10	15	74	50
C3	5	10	78	10
C4	12	15	18	10

Figure 4: Prototype corrector MPS.

The other hardware modules are standalone to each MPS. The MPS has a character LCD for display the basic information like set-current, interlock status, etc.

The cross effect tests, like step current set, bewteen MPSs in a same shlef were tested. We found that each MPSs were fully isolated in the cross coupling issues.

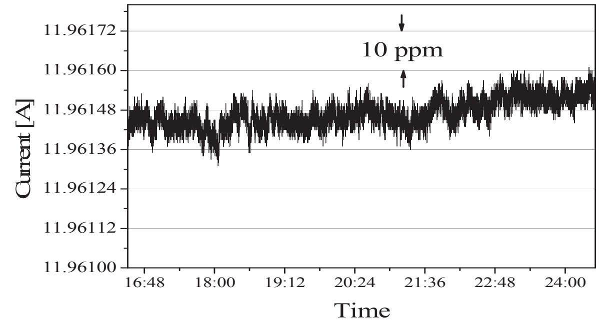

Figure 5: Long term stability of corrector power supply.

Figure 5 shows the long term current stability of corrector MPS. The current stability with the load was less than 20 ppm of ±12 A output current.

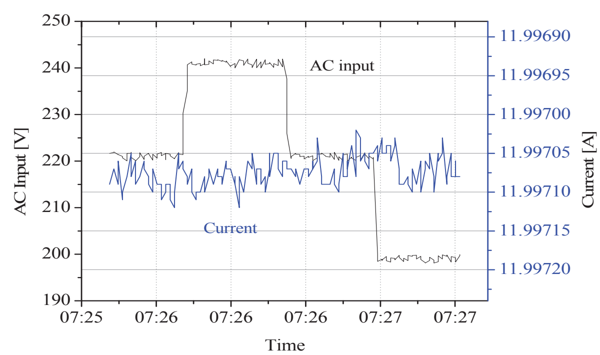

Figure 6: Resposses of the line regulation test.

Figure 6 shows the response of AC line regulation test. The AC line is change the ±10%, but current stability is not changed.

Dipole and Quadrupole MPS

The major specifications of MPSs for dipole and quadrupole magnets are given in Table 3. The total number of MPS for those magnets is 276.

Table 3: Dipole & Quadrupole MPS Specifications

MPS Type	I [A]	V[V]	Qty[ea]	Stability[ppm]
A-1	20	20	180	50 & 100
A-4	±20	20	38	50 & 100
B-1	190	110	31	10 & 50 &100
B-2	310	85	5	10 & 50
B-3	310	200	2	50

DAWON have manufactured the dipole and quadrupole power supply and prototype power supply has fabricated as shown in Fig. 7. This prototype A-1 MPS has a character LCD for display the basic imformation of MPS set-current, interlock status, etc.

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Figure 7: Prototype A-1 power supply.

The long term current stability of A1-type, power supply was measured as shown in Fig. 8. The current stability was less than 50 ppm of 20 A output current for 2.5 °C ambient air temperature change.

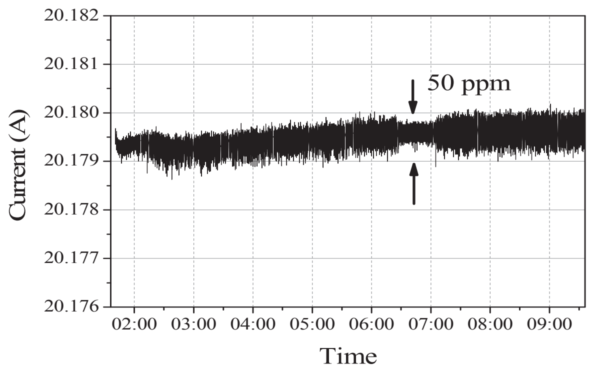

Figure 8: Long term stability of A-1 type power supply.

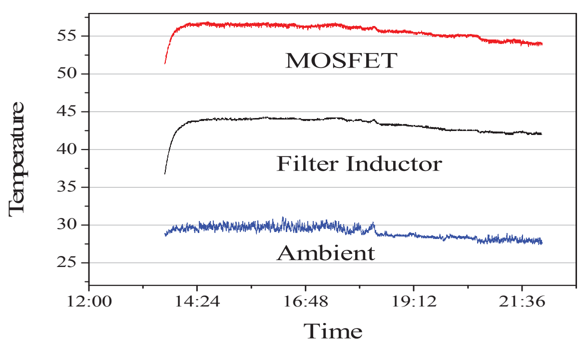

Figure 9: Temperature change of major component of A-1 type power supply.

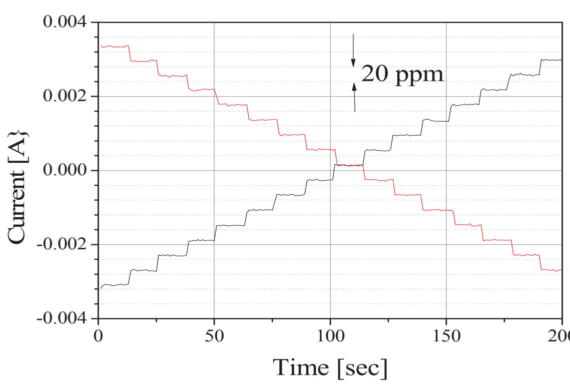

Figure 10: Zero cross response of the A-1 type MPS.

Figure 9 shows the major components operating temperature. It was measured to verify the stable operation for low MTBF (mean time between failures). The MOSFET surface temperature is about 56 °C and filter inductor is about 43 °C. It was normal operating range for reliable life time of MPS

Figure 10 shows the zero cross response of the A1-type MPS. When 20 ppm step of the input current was increased from -0.003 A to 0.003 A, the MPS showed good output responses. Figure 11 shows the reproducibility response of A-1 MPS. The output current is changed from 10% of maximum output current to maximum output current for 1 minute interval. It shows the good response.

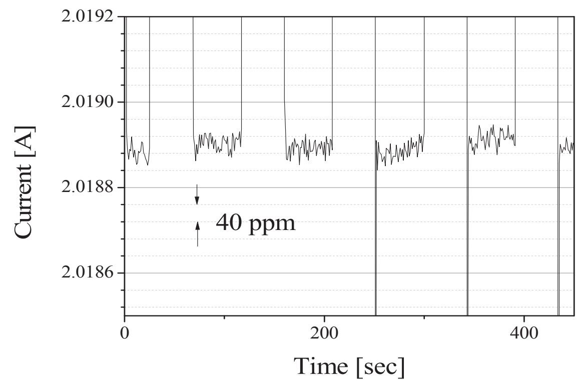

Figure 11: Reproducibility response of A-1 MPS.

CONCLUSION

This paper described the overall MPS requirements, control scheme, MPS assembling, test results, installation plan for PAL-XFEL. In factory stage, the acceptance test will focused on the power circuit. After the 8 hour-operation at 100% normal current, MOSFET and filter inductor temperature was checked. The temperature change is less than 20°C for A-1 type power supply. The experimental results with the assembled PS showed the high stability. The short term stability is about 10 ppm and long term stability for eight hours is about 50 &10 ppm each. These MPS included the small web server to make easy maintenance. The MPS will be installed from Aug., 2015 and the operation tests will begin in Dec., 2015.

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