PERFORMANCE OF THE PAL-XFEL HIGH PRECISION MAGNET POWER SUPPLIES*

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Abstract

In the PAL-XFEL, the total number of 632 of magnet power supply (MPS) have been operating since 2016.

High current unipolar MPSs (>100A) were configured buck mode with single power stack or two. The corrector MPSs for low current were the H-bridge type for bipolar current driving. The nine different types of MPS were installed for beam dynamics in the PAL-XFEL machine. All MPSs had been tested and confirmed their performances before installation.

We described here that the configuration and status of the MPS operation after installation on 2016.

INTRODUCTION

The PAL-XFEL was finished the installation at the end of 2015. The PAL-XFEL consisted mainly of a photocathode RF gun, 51 klystrons and modulators, 174 accelerating structures, and so on. Next to the 10-GeV linac, Twenty undulators were installed in the 240-m long undulator hall.

It had been commissioning stage last year and this year it achieved almost the required specifications.

The PAL-XFEL requires low beam-emittance (< 1 μm·rad), ultrashort bunch length (~50 fs), high peak current (~4 kA), high stability of beam energy (< 0.01%), and measurement and steering of beam trajectory within micrometers (< 2 μm) [1].

The PAL-XFEL will open the beam lines, hard X-ray and soft X-ray, to the user at the second half this year.

Therefore, PAL-XFEL needed the high stable and precision magnet power supplies (MPSs) for beam orbit control. The MPSs were grouped into five categories that were corresponding to the seven kinds of dipole and eleven kinds of quadrupole magnets.

And four kinds of power supplies for corrector magnets and trim coils. Table 1 shows the main specifications of the power supplies installed for the PAL-XFEL magnets.

Table 1: PAL-XFEL MPS Specification

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
C-1	5	12	262	50
C-2	10	15	74	50
C-3	4	9	78	10
C-4	10	15	18	10

The total number of MPS which were installed was upto 632.

B-3 TYPE POWER SUPPLY

There were five dump magnets at the end position of the undulator to dump the beam. These five magnets were connected in series and installed with a little curved shape to follow the beam trajectory to the underground direction.

The B-3 type MPS feed the current to these dump magnets as shown Figure 1. It had a rectifier configured with two Delta and Wye connections in series in order to make a DC voltage for the inverter stacks. The next to the rectifier, two inverter stacks were assembled which were operation in parallel by bi-phase switching mode. The switching frequency of the B-3 type is 12.5 kHz. A resistive soft start system limits the inrush current during power on.

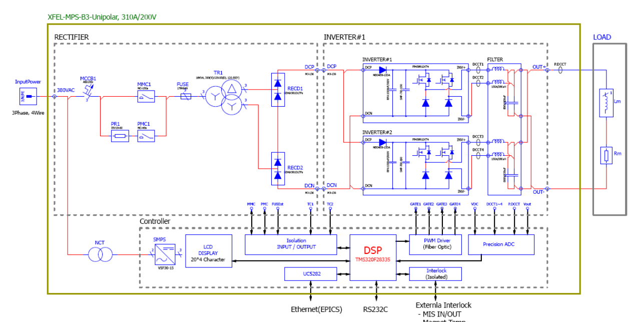

Figure 1: Block diagram of the B-3 MPS.

A full digital controller was adopted with built-in embedded epics IOC function. This power supply was assembled in a standard rack including input transformer, which had a volume of W600 x D1200 x H2100.

A AND C TYPE POWER SUPPLY

There were bipolar MPSs for the corrector magnets, trim coils and some of quadrupole magnets. These bipolar MPSs were divided into two types as A-type for quadrupole magnets and C-type for corrector magnets and trim coils. The corrector MPSs were named C-type which were divided into four types depending on their output current and voltage. The four C-type MPS were installed in a standard shelf which height was 3 U. The system configuration of the C-type MPS is shown in the Figure 2.

The input stage is switching-mode power supply (SMPS) with a damped low pass filter to get good output stability. The bandwidth of the input filter should be less than 30 Hz with a small under damp. The output stage is H-bridge topology using the four FETs with cascaded low

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pass filters to make the output current smooth and remove the switching noise [2]. The output stage was isolated to the control circuits in order to minimize the switching noise influence. The FET switching frequency for C type MPS is 50 kHz and A type MPS is 25 kHz.

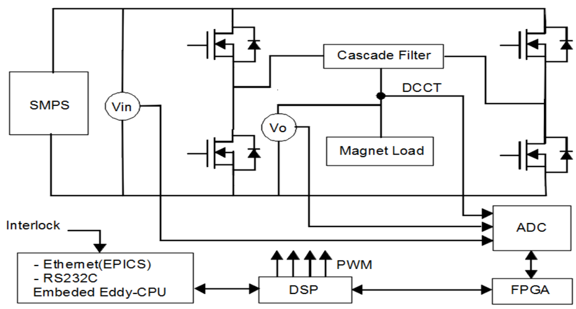

Figure 2: The block diagram of the C-type MPS.

CONTROL SCHEME

The control loop of the MPS had two loops. The one was an inner voltage loop and the other was an outer current loop as shown in Figure 3. An outer current feedback loop and inner voltage feedback loop was applied to the MPS compensator. The inner voltage loop rejects the voltage fluctuations at the magnet load. The voltage loop has a smaller time constant than that of the current loop so it can be considered as constant by the outer current loop. The control loops were executed at every PWM switching frequency.

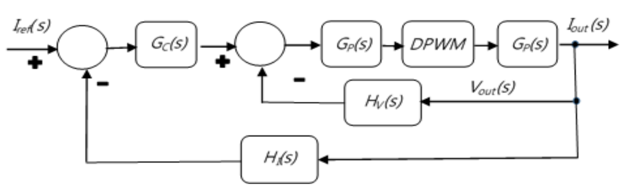

Figure 3: Control loop diagram of the MPS.

The DSP TMS320F28335 from TI Co was used to control the duty of the PWM and to interface surrounding peripherals.

The normal PWM is about ~12 bit at the switching frequency of 20 kHz. But it was increased to the 18 bits using the micro edge positioning (MEP) technology which was a function ported in the DSP [3]. It can offer the sufficient resolution for the high stability.

The MPSs communicated with the main control system by the Ethernet through the UC5282 daughter board from the ARCTURUS Inc. And it has RS232C on the front panel to monitor the MPS status at the site

All MPS are equipped with latched interlocks to detect both MPS and magnet abnormal conditions, such as DC link under voltage, overvoltage, heat sink over-temperature, over current, magnet over-temperature, cooling-water flow loss and so on [4].

Figure 4 shows the man-machine interface(MMI) for MPS operation, which is implemented by Control System Studio (CSS).

Figure 4 showed the major parameters to the MPS interface: from the left, PV list, set current, read back current, load voltage and operation status.

GUN				
INJ:MPS:SGUN	125,03000	125,03107 A	13,654209 V	Normal
INJ:MPS:CH01	0,18400 A	0,18401 A	0,22774 V	Normal
INJ:MPS:CV01	-0,04900 A	-0,04898 A	-0,08308 V	Normal
INJ:MPS:CH02	-0,00900 A	-0,00900 A	-0,02065 V	Normal
INJ:MPS:CV02	0,15900 A	0,15900 A	0,18425 V	Normal

Figure 4: The MMI for MPS operation.

The color of the set current box was changed when the difference between set and read back current was larger than the pre-defined specified value. Thus it worked as alarm.

Further status information and controls can be accessed by the normal button. This button is pop up the individual control panel to set or read the statuses.

The generic MPS interface is mainly used for fault handling of these MPS.

PERFORMANCE OF POWER SUPPLY

The major specifications of MPS were examined for short term stability, long term stability, zero cross response, reproducibility, line regulation, and so on.

Testing equipment was based on HP3458A digital voltmeter from Agilent Co. with an external DCCT STH 600 from Danfysik.

The test results showed that all MPSs met the given specifications such as current set, reproducibility, zero cross and so on

The acquired test results for the long term stability by the MPS types showed: ① C-type is 20 ppm; ② A1-type is 50 ppm; and ③ B1-type is 30 ppm.

Figure 5 shows the long term current stability of the B-3 type MPS measured at site with the installed magnet. This stability was about less than 30 ppm at 223 A of output current for 36 hours.

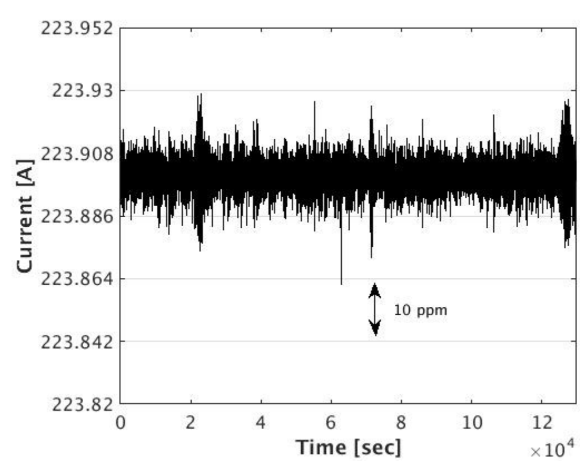

Figure 5: Long term stability for 36 hours of B-3 type MPS.

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Figure 6 shows the installed power supplies at the gallery. All MPSs have a character LCD for display the basic imformation of MPS like set current, load current and output voltage, etc. LEDs on the front panel also showed the operation status, communication status, interlock status, etc.

Figure 6: PAL-XFEL magnet power supplies at site.

FIRST YEAR OF OPERATION

Total 634 MPSs were operational mode in 2016. Figure 7 shows the interlock sources happened during the 2016 year. Total number of interlock is 28. In early stage, there were some communication errors between DSP and UC5282 Board. Almost all of interlock was solved by reset command at consol.

First year of operation pointed out a few problems mainly related to random failures of some components (IGBT's, ADC board, etc.) without any serious consequence and promptly repaired in collaboration with the builders [5].

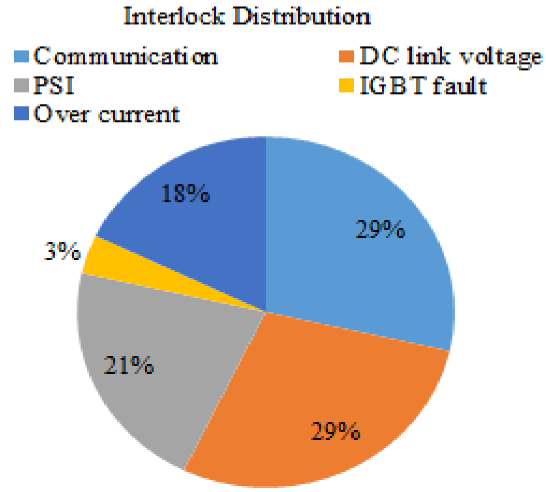

Figure 7: Interlock distribution.

CONCLUSION

This paper described the MPS requirements, structures, control scheme, MPS site first year operation results for PAL-XFEL. The operation results with the installed MPSs showed the high stable operation without serious problem. The short term stability is about 10 ppm and long term stability for 36 hours is about 30 ppm, respectively. These MPSs included the small web server to make easy maintenance. Total 634 MPSs are in operational mode now.

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