ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP028

RESEARCH PROGRESS OF POWER SUPPLY SYSTEM IN HALS *

Z. X. Shao, H. Y. Zhang, P. Liu, G. W. Liu, H. Gao, L. Wang†
NSRL, University of Science and Technology of China, Hefei, CHINA

Abstract

Hefei Advanced Light Source (HALS) is the fourth-generation light source in China's planning and construction. In order to achieve the diffraction limit of the emission and improve the beam quality, the research on magnet power supply (MPS) technology is essential. We have designed a variety of solutions for different power supplies. We designed the first version of the high stability power supply control card. The first version of the high-stability power supply control card was designed and tested with a small power module. Our pre-research system has developed a corrector magnet power supply with a small signal response bandwidth higher than 10 kHz. The developed prototypes use self-developed controllers, and most of the test results can meet the requirements. This article describes the progress of the HALS power supply system.

INTRODUCTION

International accelerators have been thoroughly researched on magnet power supplies [1-3]. The HALS pre-research power system is pre-researched around the high-precision DC stabilized current power supply and fast-response corrected magnet power supply involved in the HALS magnet power supply system. The specific design specifications are shown in Table 1.

According to the development content and acceptance indicators specified in the mission book, we have carried out the design and development of the following prototypes and control cards:

(1) Digital controller of ultra-high stability power supply

It includes the following parts: high-precision analog-to-digital converter, digital regulator control algorithm, high-accuracy pulse width modulation signal, remote control communication interface selection and digital signal processing system implementation [4].

(2) Digital controller of fast response power supply

The main difference from the previous controller is the communication between the control card and the sampling card and the implementation of the remote communication method. The core chip selection is also different [5].

(3) Fully digital power supply prototype

Including two sets of dipole MPS prototypes, two sets of quadrupole MPS prototypes and three fast-corrector switching power supply prototypes, and two fast-corrector linear power prototypes. Multiple power supplies work at the same time to check the anti-interference ability and stability of the digital control system and power supply equipment.

* Supported by "the Fundamental Research Funds for the Central Universities" (WK2310000064) and the Hefei Advanced Light Source Pre-research Project.
† Corresponding author (email: std@mail.ustc.edu.cn)

Table 1: HALS Pre-Research Power Supply Prototype Design Indicators

Category	Parameter	Specifications
High stability MPS	Long-term stability (8h)	10 ppm
	Current ripple (50Hz and above)	5 ppm
	Output current resolution	10 ppm
	Current reproducibility	20 ppm
Fast response MPS	Small signal response bandwidth	5 kHz
	Output current resolution	20 ppm
	Long-term stability (8h)	100 ppm
	Given response rate	10 kHz

POWER SUPPLY DESIGN PROGRESS

Dipole MPS

The main loop topology of 800 A/200 V dipole magnet power supply prototype adopts 12-pulse isolation rectifier, simultaneously in parallel with the Buck chopper module. The number of stages is based on the specific output current. 12-pulse isolation rectifier reduces the power supply ripple. The chopper circuit is controlled in parallel by multiple power modules, and the equivalent switching frequency of the power supply output can be n times the actual switching frequency of the IGBT device. The frequency increasing filter circuit is small in size and low in frequency ripple. The principle block diagram is shown in Figure 1.

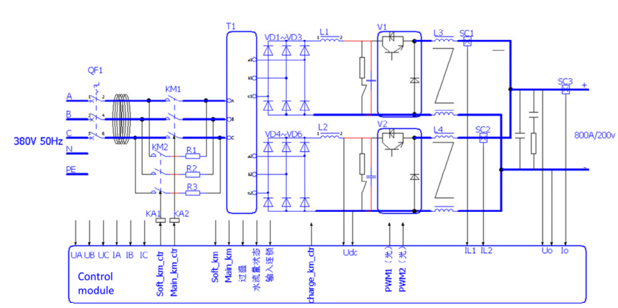
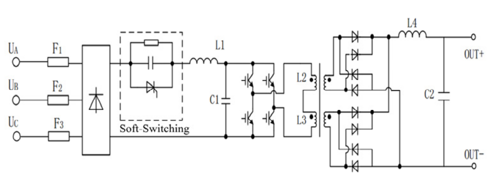


Figure 1: Block diagram of dipole magnet power supply.

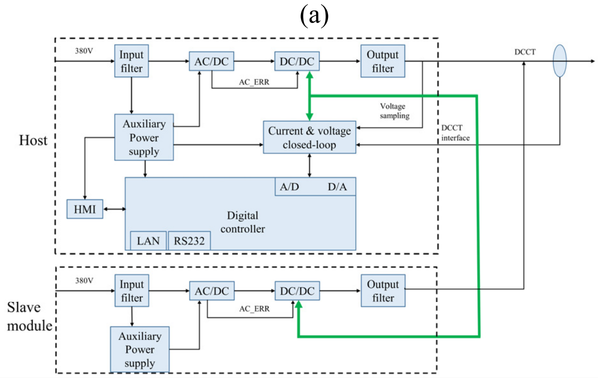
ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP028

Quadrupole MPS

The quadrupole magnet power supply prototype 250 A/40 V main circuit uses two modules in parallel, of which each module 125 A/40 V consists of rectification and high frequency DC/DC converter. There are 2 designs on the structure. The first solution uses a standard 4U chassis and is water cooled. The second solution uses two 19-inch 1U modules stacked, and the power circuit uses silicon carbide devices for air cooling. The principle block diagram of the two schemes is shown in Figure 2. Both prototype control schemes are digital plus analog control. The voltage loop and current sharing loop of the core adopt analog adjustment, which can improve the speed of the inner loop, facilitate peak current control and reduce voltage ripple [6]. The digital current outer loop avoids the effects of analog control temperature drift and device aging, and can be adjusted by software. And optimizing the parameters of the control loop ensures that the accuracy of the power supply reaches 10 ppm. At the same time, the feedback loop adopts precise temperature control. The ADC operating temperature is controlled at ±0.5 °C to reduce the temperature of the power supply. The input and output filters use a common-mode filter to reduce the noise of the system. Key chips such as ADCs and DACs communicate with the CPU through digital isolators to ensure minimal interference to the system.



(a)



(b)

Figure 2: Block diagram of the two schemes. (a) Using 4U module. (b)Using 1U module.

Fast-response MPS

The fast response power supply provides excitation current for the fast-track feedback corrector magnet, requiring fast response. At the beginning of the power supply design, through research, taking into account the power supply bandwidth, current ripple and other technical indicators, decided to use switching power supply and linear power supply two topologies to develop separately to ensure the realization of engineering indicators [7-8]. At present, the first version of the self-designed digital linear power principle prototype has been completed. The core of the power supply is the high-precision analog given chip AD5791, which has a 20-bit resolution and can meet the design target's current setting resolution better than 20 ppm. The controller uses the ARM core STM32 integrated circuit chip to replace the conventional DSP, because the linear power supply does not require the high resolution mode PWM function, the power control does not require modules such as hardware multipliers, the STM32 has low power consumption characteristics and rich the control interface is more suitable for development. The voltage and current double closed-loop control strategy is adopted to ensure the stability meets the basic requirements. The first version of the control unit is equipped with the RJ45 interface to interface with the communication protocol provided by the control group. At the same time, the HMI based on the touch screen is developed to facilitate local control and debugging. The block diagram is shown in Figure 3.

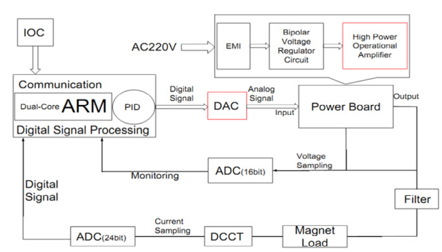


Figure 3: Block diagram of the fast-response power supply.

PROTOTYPE AND TEST RESULTS

The digital controller is the core component of the power supply, and mainly implements the realization of the power control algorithm, the generation of the PWM, the control of the feedback channel ADC and its conditioning circuit, and the functions of remote communication. The ultra-high stability digital regulator has completed the first version of the design and processing, and the controller adopts the interface form of the core board plus the sampling board plus the power board and the back board. Figure 4 shows the physical map of the digital control card.

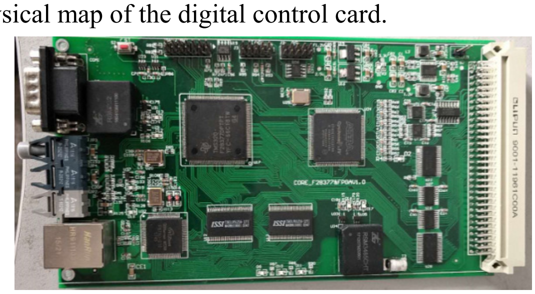


Figure 4: The digital control card.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP028

This controller has been applied to a small power supply of ±10 A/12 V and has a long-term stability of 20 ppm at room temperature. The test results are shown in Figure 5.

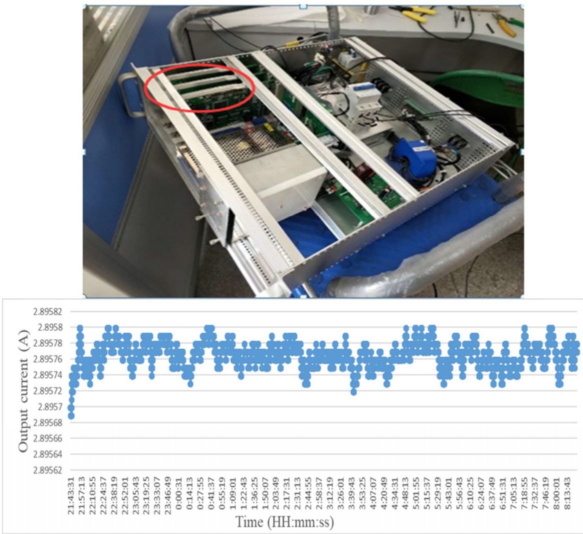


Figure 5: Stability test of the first version of the digital control card.

The prototype of the first version of the digital linear power supply uses the topology of the audio power amplifier circuit, so the frequency response can fully meet the requirements, and the 10 kHz sine wave can respond. Input and output delay is also less than 100 µs. Figure 6 shows the test results.

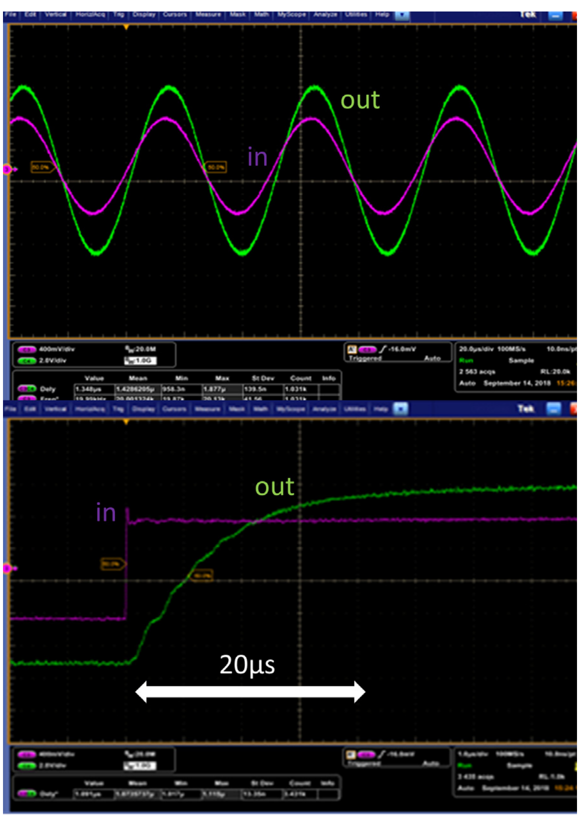


Figure 6: Frequency response test results of digital linear power supply.

CONCLUSION

At present, the HALS power supply system is progressing smoothly, and the prototype can basically reach the target. The first version of the high stability power supply has a test stability of 20 ppm. The test environment has a certain impact on the results. If we add constant temperature control, the results should be better. The fast response power supply uses a linear power supply scheme with a frequency response of 10 kHz and a rise time of 20 µs. The power loss of the linear power supply is too large, mainly due to the characteristics of the linear amplifier component operating in the linear amplification region. Using a large heat sink can take away heat, but efficiency is a problem to consider in the future. The future research focus of digital control card should be on A/D sampling constant temperature processing and algorithm optimization.

REFERENCES

[1] Jean-Paul Burnet, Power Converter Requirements, CERN Accelerator School on Power Converters,2014, http://indico.cern.ch.

[2] Yves Thurel et al., LHC POWER CONVERTERS,THE PROPOSED APPROACH, CERN, Geneva,Switzerland.

[3] R. Kuenzi and M. Emmenegger, "Bipolar 10A and 50A Magnet Power Supplies for SwissFEL", in *Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May 2013, paper MOPWA040, pp. 756-758.

[4] Choi W S, Kim M J, Jeong I W, et al. Development of high-stability magnet power supply[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2016, 822: 15-24.

[5] Z. X. Shao, H. Gao, L. Wang, and H. Y. Zhang, "Design of Beam Position Fast-Correction Magnet Power Supply for HALS", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 4967-4969. doi:10.18429/JACoW-IPAC2018-THPML124

[6] Kondo C, Hara T, Fukui T, et al. A stable pulsed power supply for multi-beamline XFEL operations[J]. Review of Scientific Instruments, 2018, 89(6): 064704.

[7] C. Mi et al., "A New Bipolar qtrim Power Supply System", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 3621-3623. doi:10.18429/JACoW-IPAC2015-WEPWI057

[8] B. Song and J. Wang, "Mathematical Modeling and Analysis of a Wide Bandwidth Bipolar Power Supply for the Fast Correctors in the APS Upgrade Controller", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 3264-3266. doi:10.18429/JACoW-IPAC2015-WEPTY004