

RESEARCH AND DESIGN OF DIGITAL MAGNET POWER SUPPLY CONTROLLER FOR HALS*

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Abstract

Hefei Advanced Light Source (HALS) is the fourth-generation radiation light source in China which is under design. Ultra-low beam emittance requires higher performance of power supply system. The power supply controller is a key part of the power system. This article describes the design and testing of high-stability power controllers and fast corrector power supply controllers. A new controller architecture is proposed for the problems of the two controllers.

INTRODUCTION

The magnet power system is the key system to ensure the stable operation of the particle accelerator. The development of particle accelerators and synchrotron sources has placed higher demands on magnet power systems [1, 2]. Accelerator magnet power relies to some extent on digital control techniques, including power on/off, condition monitoring and protection, digital setting of current, and digital closed loop control. The digital controller of the power supply also needs to be equipped with various communication interfaces for easy access to the EPICS system.

The analog control circuit has the disadvantages of low control precision, inconvenient parameter adjustment, severe temperature drift and easy aging. Analog integrated control chips also have problems such as high consumption power, low integration, and low versatility. The use of digital control technology instead of analog can avoid the above shortcomings and improve the control precision and system flexibility of the entire power supply. Digital power controllers have become a hot topic of research. SLS is the world's first fully digitally controlled device. The accuracy of the LHC's main superconducting magnet power supply has been improved with digital regulators. However, the current digital control board also has some problems, such as the PWM resolution is affected by the frequency of the digital chip, the stability of the ADC sampling feedback is insufficient, the interface is not uniform, and can only be applied to a specific power supply, etc.

In this case, we have designed several new magnet power controllers for high-precision quadrupole and sextupole magnet power supplies and fast-correcting magnet power supplies. And finally try to integrate all the functions on the same type of control board. The high-precision control board was developed based on the mode of DSP plus FPGA, and the fast corrector control card was developed using ARM STM32 chip as the core. Finally, combining

the advantages of the two cards and analyzing the deficiencies, a new control card scheme is proposed. In addition, the track feedback system has high requirements on the real-time response characteristics of the power supply. We try to integrate the real-time Ethernet POWERLINK protocol on the power control card, which makes the remote control faster and simpler. This paper introduces the research progress, design scheme and related test results of the control card in detail.

DIGITAL CONTROLLERS

High Stability Control Card Design

The controller consists of the core card, sampling card, power card and interface card modules. The core control board adopts the structure of DSP+FPGA. TI's dual-core DSP chip TMS320F28377D is selected. The single-core main frequency is 200 MHz. All communication functions of the control board are completed by the sub-core, and other functions are completed by the main core. Using ALTERA's Hurricane 4 Series FPGA-EP4CE10E2217, it has 91 programmable I/O interfaces, which can be satisfied for most logic control. The AD7606 and AD7634 are selected respectively to complete voltage and current sampling, communicates with the sampling chips by the full rate of the FPGA, and then reads from the DSP to the FPGA through the parallel port, and the read rate can be adjusted. Figure 1 shows the schematic diagram of fast correcting magnet power supply.

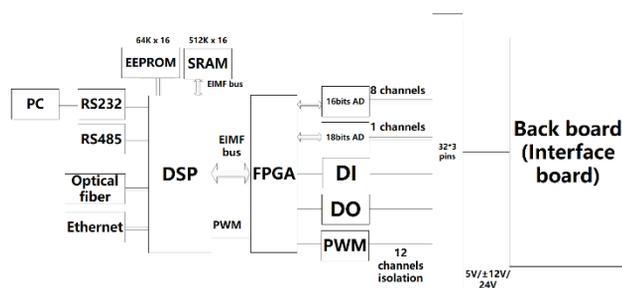


Figure 1: Schematic diagram of high stability control card.

The controller adopts double closed loop control of output voltage and output current. The current is given by the computer, and the error value of the current is obtained by comparing with the feedback current. The output voltage loop is calculated by the output current loop PI regulator, and then the output voltage value of the H-bridge can be obtained by the voltage loop PI regulator.

To ensure that the control system is not affected by the sampling noise, digital filtering is added before the current feedback and voltage feedback respectively. At the same

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time, to avoid the output overvoltage of the converter, limiting protection is added to each PI regulator. Figure 2 shows the control strategy flow chart.

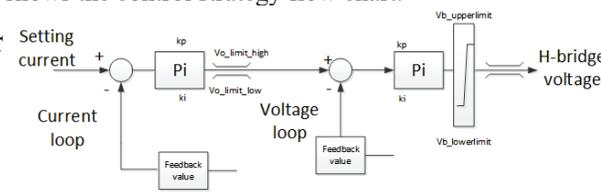


Figure 2: Control algorithm block diagram.

Fast-response Control Card Design

The fast corrector magnet power supply is divided into two types: linear and switch. The digital linear power supply controller is relatively simple. The core device is a high-precision, high-stability 20-bit DAC chip AD5791. At the same time with a dedicated power chip and peripheral drive circuit. Since the linear power supply does not need high-precision PWM signals, we chose the ARM-based microcontroller unit (MCU) STM32 as the core control chip. The STM32 MCU has a variety of communication interfaces. We use the AD7634 as a current sampling chip and the MAX1300 as a voltage sampling chip. At the same time, the analog PI regulator is integrated on the controller, and the regulator is mainly composed of high-precision operational amplifiers. The physical map of the controller is shown in Fig. 3.

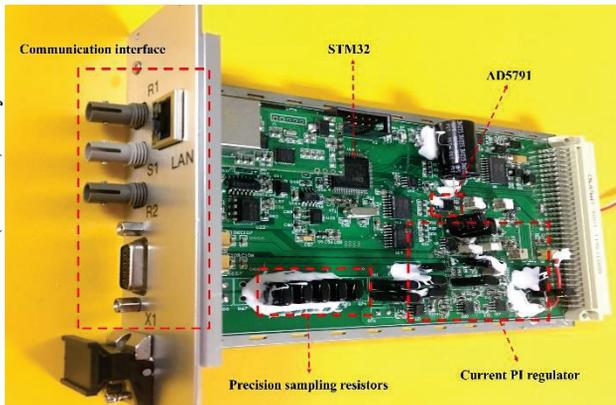


Figure 3: The physical map of the fast-response controller.

For digital linear power supplies, the given stability directly determines the final stability of the power supply. Therefore, we have tested the long-term stability of the digital control card DAC output separately. The test results are shown in Fig. 4. The result shows that the stability of the AD5791 can be kept within 1 ppm when the full-scale output is more than 8 hours, indicating that the digital control card design and board layout are satisfactory.

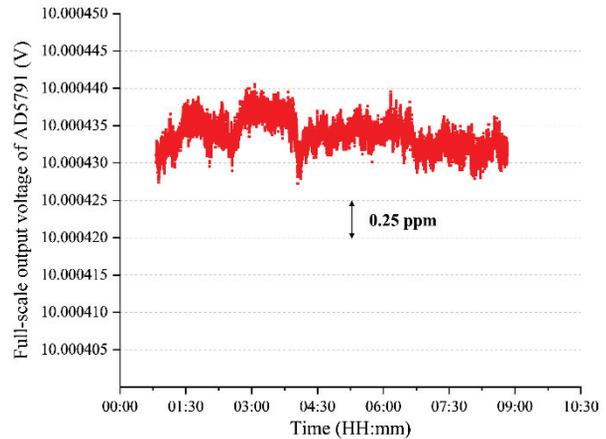


Figure 4: Long-term stability of the output voltage of the AD5791.

NEW CONTROLLER COMBINED WITH REAL-TIME ETHERNET

New Digital Control Card Design

The problems of the previous controller scheme mainly include the following: 1.Can only be applied to specific power sources. 2.The accuracy and stability of the ADC chip are not enough. 3.The real-time nature of remote control is too bad.

To solve these problems, we have proposed a new digital controller solution that can be applied to both digital linear and switching power supplies. The controller is equipped with both high-precision ADCs and a high-precision DAC, as well as high-resolution PWMs to drive switching devices. The block diagram of the new controller is shown in Fig. 5.

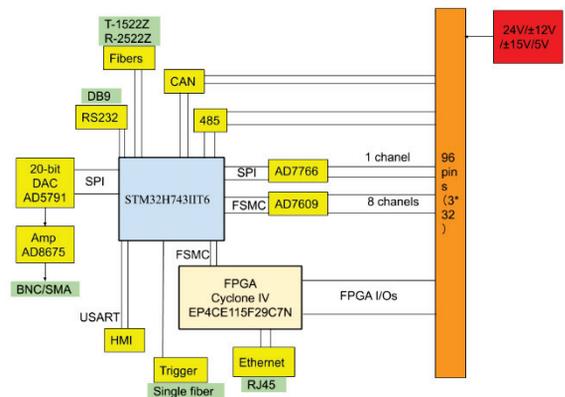


Figure 5: New controller block diagram.

The MCU adopts ST's STM32H7 series, with a single core frequency of 400 MHz, and the FPGA uses ALTERA's EP4C. FPGA adopts serial mode to expand one AD7609, 16-bit precision, sampling rate 200 kpsp for voltage sampling; FPGA uses serial mode to expand a differential AD7766, 24-bit precision, input range programmable for current sampling; Expand the AD5791, 20-bit DAC for

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voltage setting; the power supply is externally generated by ± 12 V and 5 V, and internally generates a 5 V linear power supply to supply power to the ADC. In this scheme, both STM32 and FPGA can perform calculations, and both can generate PWM waveforms.

Real-time Ethernet Applications in Power Supply

An important function of the digital controller is to interface with the EPICS system, making the power system easier to remotely control. Especially for the fast orbit feedback system, in the track feedback system, the position of the beam needs the magnet power supply to give a response in real time. At this time, the time of the remote communication is critical, the conventional Ethernet speed is not fast enough, and the protocol is not integrated into the power supply.

Ethernet POWERLINK (EPL) is an open source real-time Ethernet built on standard Ethernet absolutely and allows data transfer with predictable timing and precise synchronization. The control system of HALS is a distributed system based on EPICS. Therefore, if the HALS correction magnet power supply can be based on the EPL design under the EPICS architecture, the real-time performance of the feedback system will be much improved. The low-level hardware drivers of EPL including the Medium Access Control (MAC) Layer and the Physical Layer (PL) are fully compliant with IEEE 802.3. The EPL can support the transmission medium of the Fast and Gigabit Ethernet. The OSI model of EPL is presented in Fig. 6 [3].

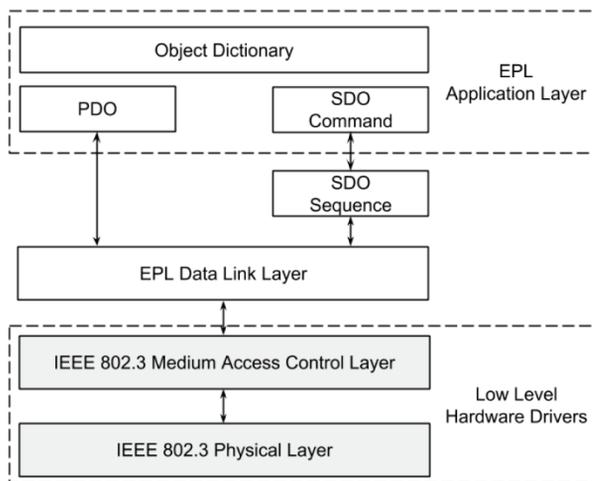


Figure 6: OSI model of EPL.

The National Synchrotron Radiation Laboratory Control Group has designed a prototype to verify the real-time performance of EPL. The experimental results show that using EPL as a protocol, the trigger response delay can reach 400 μ s or even shorter. Because the digital controller of the power supply contains the FPGA, if the EPL protocol can be directly run on the power control card in the future, the equivalent of each power supply is the EPL node, which is not only convenient to control, but also better in real-time.

CONCLUSION

In this paper, we introduced the research progress of digital controller of Hefei advanced light source magnet power supply system. The high-stability power controller and the fast-correction power controller have been designed and tested. For the existing problems, a new general-purpose digital controller architecture is proposed, and the real-time Ethernet protocol can be integrated into the power supply. It provides a new idea for future power controller design.

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