ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP014

DIGITAL CONTROL SYSTEM OF HIGH PRECISION MAGNET POWER SUPPLY FOR SPRING-8-II

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Abstract

Next-generation synchrotron radiation sources, such as SPring-8 upgrade, require various kinds and large amounts of magnet power supplies, and most of them are require to be highly stable. In order to provide many power supplies with a reasonably low cost in a short production period, we developed a common current control system using a digital feedback control technology. The system consists of a high-precision analog-digital converter (ADC) circuit and a feedback controller using a field programmable gate array (FPGA). We tested a DC power supply equipped with the above digital feedback control system, and confirmed that the current ripple could be suppressed to less than 5 ppm (pk-pk). We also prototyped a high power DC power supply with 650 A based on a modularization concept. We also prototyped a DC-link power supply for a steering magnet with synchronized current output between 3 ports.

INTRODUCTION

Next-generation synchrotron radiation (SR) sources aim to produce order-of-magnitude lower emittance than those by the third generation SR sources. For the purpose, multi-bend lattices that include many magnets are designed [1,2]. One of tendencies from the magnet point of view for the new lattices is that magnets are combined-functioned to fit in the high packing factor lattice; some magnets are supposed to generate dipole and quadrupole magnetic fields in a single element, and some is a sextupole magnet embedded with a steering function. Also, required precision of the magnets may be higher because each magnetic strength tends to be higher. Accordingly, various kinds and large amounts of power supplies need to be newly designed and fabricated.

In case these power supplies (PS) are designed with traditional analog feedback technologies, the control circuits are to be designed for each PS, and a large cost and a long period of developments are required. For the reason, we introduced a digital feedback control technology. The digital control for the accelerator magnet has been developed for longer than 20 years [3].

We have newly developed a digital feedback control system which can be applied to various magnet power supplies. By using a high precision analog-digital converter (ADC) circuit, the precision of the PS is guaranteed. By using a field programmable gate array (FPGA), the system can be remodelled easily for various model of PS. Thus, we can suppress the cost and period for the developments.

In this report, we present the design, manufacturing and test results of our high precision power supplies and the digital control system.

CONCEPT OF MAGNET PS

Magnet

Magnet system of synchrotron radiation is composed of a variety of magnets in a wide range of output current. The multi-pole magnets are grouped to families, each of which are driven by one high power PS with the driving current of from 10 to over 200 kW, and each current precision is as high as 20 ppm (pk-pk) or better.

A number of small current magnets, like as a steering magnet or a skew magnet, are driven by small power PSs individually. For the PS, the required current precision is less than 50 ppm (pk-pk). In some sextuple magnets, auxiliary coils are driven for steering function, and the current between the 3 pair coil should be balanced to suppress the multi-pole field. The small power PS also is required a function of fast current modulation for a beam-based aliment. Therefore, the controller of the PS is required to have a flexibility to accommodate with the functions.

Overview of Digital Feedback System

Our digital feedback control system can control the current with high precision and can be used to various magnet PS. A schematic layout of digital feedback system is shown

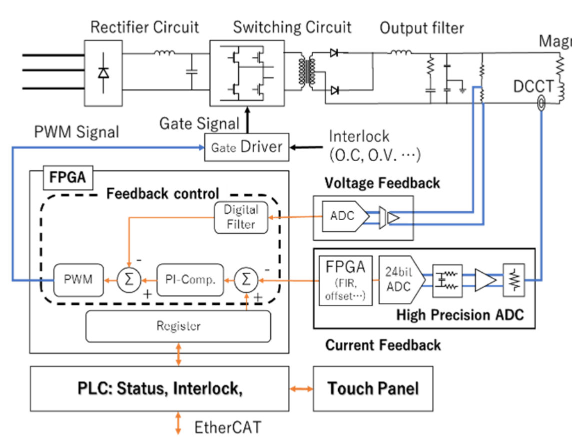

Figure 1: Schematic diagram of an overview of digital feedback system.

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in Fig. 1. The system is composed by highly precision AD circuit and feedback controller by FPGA.

Because the accuracy of the ADC circuit limits the precision of the PS, we developed a highly precision ADC circuit with the accuracy of less than 1.6 ppm (standard deviation: *STD*). We also developed a simple feedback model of FPGA. It can be easily remodelled according to the power circuit. We provide the ADC circuit and the feedback model to a manufacture of the PS to save the cost and period of PS development.

DCCT and ADC Circuit

We employed two DCCT for measuring the output current. For small current PS, we used UP-200A by Soft Energy Controls Inc. [4], which has low noise and high cost performance. For the high power PS, we use DS600 by Danisense A/S [5], which has low noise and good stability.

The measurement accuracy of the ADC circuit is required to be higher than the precision of the PS. The theoretical signal-to-noise ratio (*SNR*) in AD conversion is expressed as

$$SNR(dB, STD.) = 6.02N + 1.76 + 10\,log_{10}\frac{fs}{2BW}$$

where, N is a bit number of the digital data, fs is a sampling frequency and BW is a band width. To achieve the accuracy within 1.6 ppm (*STD*), the bit number is needed to be larger than 18-bit with the 100 kHz sampling rate and 1 kHz bandwidth. In consideration of a margin, we utilized a 24-bit ADC-IC (LTC2380-24 by Analog Devices). To suppress circuit noise, the ADC-IC and other analog devices were surrounded by solid ground pattern and a metallic shield cover, as shown in Fig. 2.

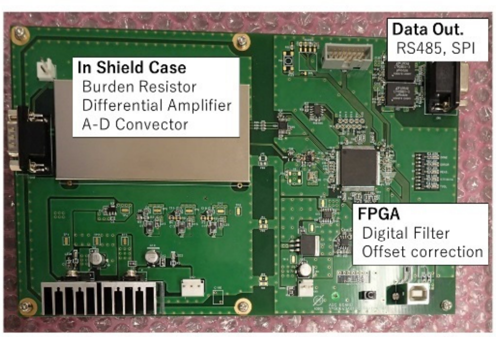

Figure 2: Overview of high precision ADC circuit.

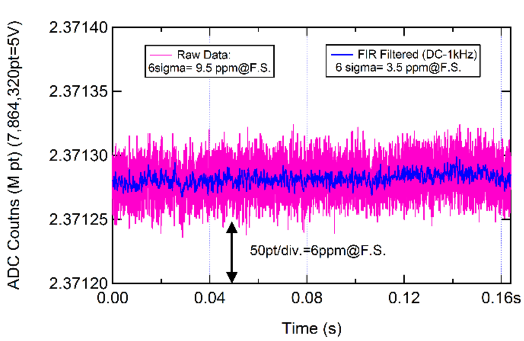

Figure 3: Waveforms of sampled raw data (pink) with 100 kHz, and filtered data (blue) with DC-1kHz in off-line analysis.

In a FPGA on the ADC circuit, an offset and gain error of the digitalized data is corrected, and a low pass filter of FIR is applied. The data is outputted for the feedback controller with 100 kHz rate by a differential signal (RS-485).

We measured the noise amplitude of the ADC circuit, and the measured waveform is shown in Fig.3. The fluctuation was 0.6 ppm (*STD*) in the range from DC to 1kHz.

Feedback Controller in FPGA

We chose a FPGA for the digital processer. FPGA has a flexibility, high speed, and parallel processing. In the current feedback process, the digitalized current data is proceeded by a digital proportional-integral (PI) compensator to generate pulse-width-modulation (PWM) signals and gate signals for the switching devices. An output voltage feedback system is prepared as an option.

This controller system is made to resemble to a traditional analog-feedback controller, so that it is easily understandable by operators. Each process is designed with intellectual property (IP) cores, and can be easily remodelled by using a personal computer, according to the topology of the power circuit.

Demonstration of the Digital Feedback System

To demonstrate a highly precise DC power supply with a current ripple of 10 ppm (pk - pk) by the digital feedback system, we produced a test PS with 200 A, 30 V. The photograph of the PS is shown in Fig, 4.

We examined the PS connected to a magnet with 1.2 mH, 34 mΩ. In a rated operation, FFT amplitude of the current ripple measured is shown in Fig. 5. The results indicated the ripple of less than 3 ppm (pk-pk) from 10 Hz to 1 kHz. The result satisfied the requirements of the magnetic PS.

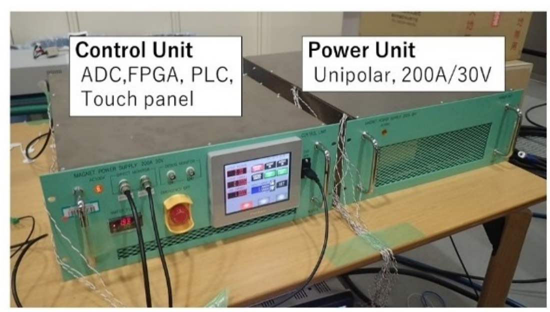

Figure 4: Overview of test PS using the digital feedback control system.

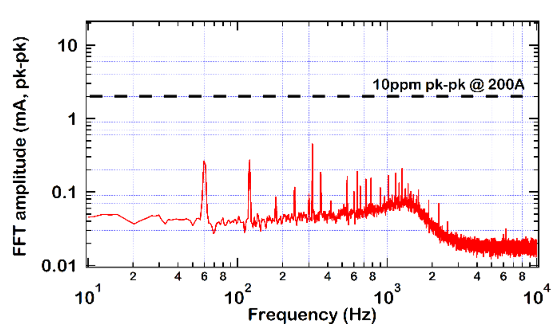

Figure 5: FFT amplitude of output current at 200 A operation.

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PROTOTYPE PS

We also developed a high power PS for family magents and a DC-link type PS for a steering magnet as prototype PSs. In the Table 1, the main specifications are liseted. In this section, we present the design concepts of the PSs.

Table 1: Specifications of the Prototype PSs

Specification	High Power PS.	Steering PS
Output port	1	3
Output current	650 A, 30V	±12 A, ±12V
Current ripple	20 ppm (pk-pk)	50 ppm (pk-pk)
Temp. coeff.	10 ppm/K	20 ppm/K
Switching freq.	40 kHz	40 kHz

High Power PS for Family Magnet

The rated power of the high power PSs for a family magnet is required from 10 to over 200 kW. To develop the various rated power PS, we introduced a common module concept of the inner devices. In Fig. 6, the circuit diagram and the photograph of the PS are shown. The power circuit consists of two switching modules which include chopper circuits and high frequency filters. The control unit includes all control circuit in a chassis. Various power can be tuned by changing the number of the switching module. This design concept helps reduce the costs of production and maintenance.

We examined the PS connected a magnet with 0.3 mH, 6 mΩ, and confirmed the current ripple of less than 10 ppm (pk-pk).

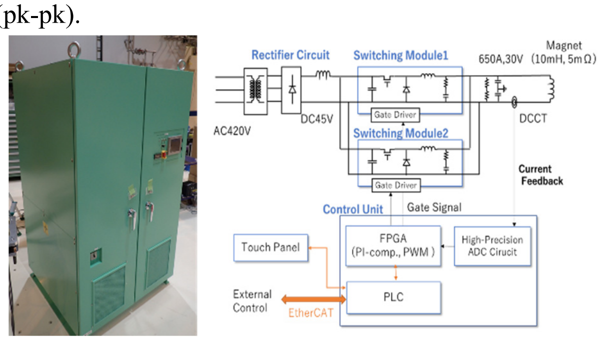

Figure 6: Picture (left) and schematic diagram (right) of the high power PS.

DC-link PS for Steering Magnet

Because the number of PS for steering magnets and other small current magnets, is larger than several hundreds, we introduced a DC-link PS system to reduce a production cost. Figure 7 shows a block diagram and a picture of the DC-link PS for the steering magnet. The system consists of a control unit with rectifier circuit, and 8 power units at maximum. In the system, a number of the rectified circuit and expensive control modules can be reduced.

The control unit provides DC power of 280 V to each power unit. The control unit has a touch panel and PLC modules to control the power units by CAN interface. The control unit also communicates with external network by EtherCAT interface.

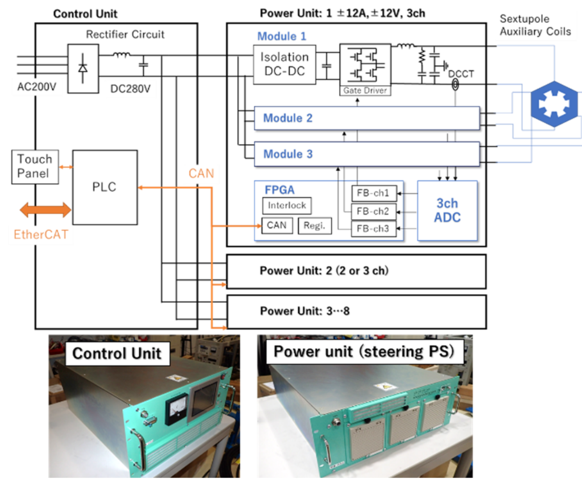

Figure 7: Schematic diagram (upper) and pictures (under) of DC-link PS system.

The power unit for steering magnet has three switching modules with +/-12 A, +/-12V. The switching module is composed of an isolation DC-DC to step down to 18V, a full bridge circuit for regulation and polarity change of the output current, a high frequency filter, and the DCCT (UP-200A). The three modules are controlled by a 3-channel ADC circuit and a feedback controller with 3-channel feedback system. The multi-port control by one FPGA realizes the synchronized control of the 3-port current, which is required of steering function of the sextupole magnet.

We performed the operation test of the PS with a dummy load, and confirmed the current ripple was less than 30 ppm (pk-pk).

SUMMARY

We developed a digital feedback control system for the magnet PS of next generation SR sources. The system consists of a high precision ADC circuit and a feedback control circuit using FPGA. We demonstrated the high precision current feedback control by using the system, and verified that the current ripple was less than 3 ppm (pk-pk). We also deveploped the high power PS with 650 A, 30 V, and DC-link PS for steering magnet with +/-12 A, +/-12 V. The current ripples satisfy the requierments.

Acknowledgment

We thanks for N. Katakura, and T. Shindo in Ohukra Corp, and Y. Suzuki, K. Ohori, S. Sasaki, K. Suda in Kudo Electric Co. Ltd., and H. Naoe and many technical staffs in Nichicon Corp.

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