DESIGN AND IMPLEMENTATION OF BIPOLAR POWER SUPPLY FOR CORRECTOR MAGNET

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Abstract

This paper presents the corrector magnet power supply for the Pohang Light Source (PLS). The required current to energize the corrector magnet was ±30 A with the high precision of ~2 ppm resolution to accomplish a stable beam orbit correction. This power supply has been implemented by a digital signal processing technology and shows the high stability and other good responses. Various experimental results such as stability, bandwidth and simulation are given in this paper.

INTRODUCTION

In accelerator, several kinds of magnet power supply (MPS) are used to maintain the beam's proper position. Magnet field strengths are controlled individually through the feedback loop comprising the beam position monitoring system. Thus for all the correction magnets, bipolar power supplies (BPSs) are required to produce both polarities of correction fields. These MPSs should have the high precision and stability for stringent specification of storage ring [1].

The power supply is equipped with a passive L-C-R filter to reduce the ripple components of the output current. The transducer senses the magnet current and provides the control signals for the regulator. The current transducer which has high precision and low drift is used. Two control loops are implemented to regulate the current in the magnet. Fast correction for the line transient is provided by a relatively fast response voltage loop [2].

The digital signal processor (DSP) combining with the FPGA had been developed which was suitable for implementing the complicated algorithms such as feedback control, digital filters, and so on. And it includes many functions to make it easy to interface the peripherals chips by the SPI, CAN, RS232C, etc. Thus the application areas of the DSP become wider day by day, especially in power conversion systems - power supply, UPS, inverter, etc.

In this paper, we present the design scheme and measured results of the fully digital-controlled high precision MPS for corrector magnet of the PLS.

SYSTEM CONFIGURATION

The system configuration of the designed MPS is shown in Fig. 1. Both Current feedback and voltage feedback are applied to improve the output current stability. We used the DSP TMS320F2808 to control the overall power supply system. The controllability of the TMS320F2808 with the micro-edge positioning technology [3] was less than 10 ppm, which satisfied the required accuracy for the MPS. The SKM300GB063D IGBTs from Semikron International Co. used for switching elements.

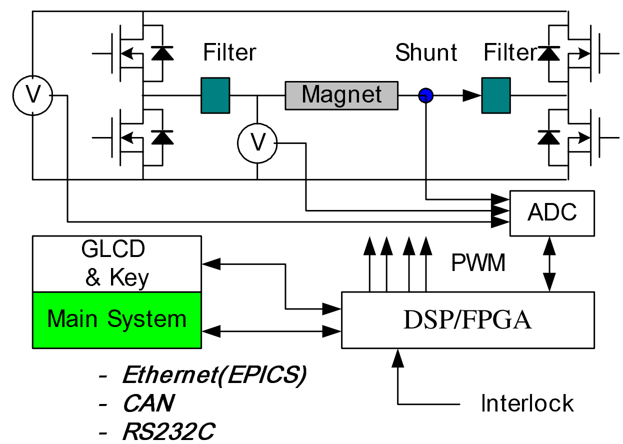

Figure 1: Functional Block Diagram.

The major board specifications are following.

DSP board specifications:
- 100MHz Fixed point TMS320F2808 DSP
- PWM : 1a, 1b, 2a, 2b, 3a, 3b, 4a, 4b
- PWM Frequency : up to 100 KHz
- Output : 24V relay control
- UC5282 Board : Ethernet (EPICS)
- Interlock : Flexibility with the Cool-Runner FPGA
- Ethernet & CAN Connector : At front Panel

ADC board specifications:
- ADC AD977A : 4 channel
- Input Range : ±5V, ±10V, 5V, 10V
- Using the Isolated DC Power
- ADC Linearity : ±2.0 LSB
- FPGA(Xilinx Sprtan3) : Generate various control signals.
- Digital to analog converter DAC714 for function test..

The output filter is composed of conventional R-L-C filter which includes an R-C damping circuit to make good filter response. The output filter and load magnet were modelled as shown Fig. 2, where the load magnet was modelled with R_2 and L_2 , and the filter circuit

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consisted of L_1, C_1, R_1 and C_2. Equation (1) shows the transfer function of the output filter [4]. The cut-off frequency of filter is about 7.2 kHz simulated using the PSPICE as shown in Fig 3.

$$\frac{V_o}{V_s} = \frac{b_2(s-z_1)(s-z_2)}{a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s^1 + a_0} \qquad (1)$$

where the details are in [4].

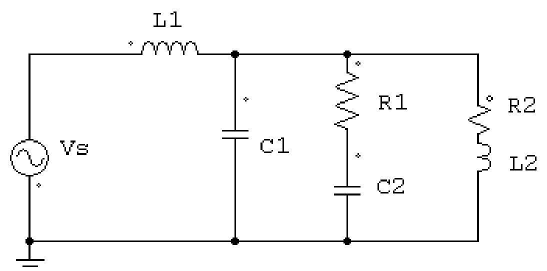

Figure 2: Equivalent circuit of output filter and load magnet.

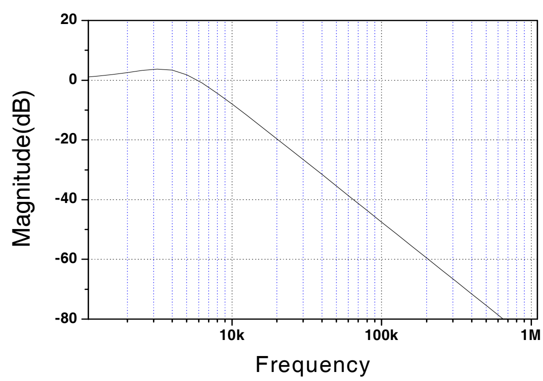

Figure 3: Frequency response of output filter and load magnet

The control loop for the designed MPS is given in Fig. 4. The coefficients of PI compensator $G_c(s)$ were determined directly using the characteristic equation of the control loop. The closed-loop control system for the MPS is given Figure 4.

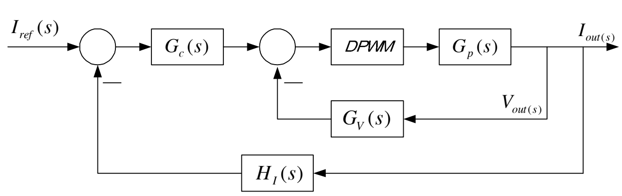

Figure 4: Block diagram of complete current loop system.

The closed-loop transfer function of the power supply is given by:

$$I_{out}(s) = I_{ref}(s)\left(\frac{G_c(s)G_{in}(s)H_I(s)}{1+G_c(s)G_{in}(s)H_I(s)}\right)$$

while the equivalent transfer function of the inner loop $G_{in}(s)$ is $G_{in}(s) = \dfrac{G_P(s)G_V(s)}{1+G_P(s)G_V(s)}$.

For the cascade control loop:

- The inner voltage loop used to reject the voltage fluctuation of the output stage.
- In cascade loop control, the inner voltage loop has a small time constant comparing to outer current loop.
- The inner voltage loop in a cascade-control should be tuned before the outer current loop.
- After the inner voltage loop is tuned and closed, the outer current loop tuned using the responses of the inner loop.

The internal signal interfaces and external communication schemes are shown in Fig. 5. The one of the Ethernet, CAN or RS232C was possible for controlling and monitoring from the host computer.

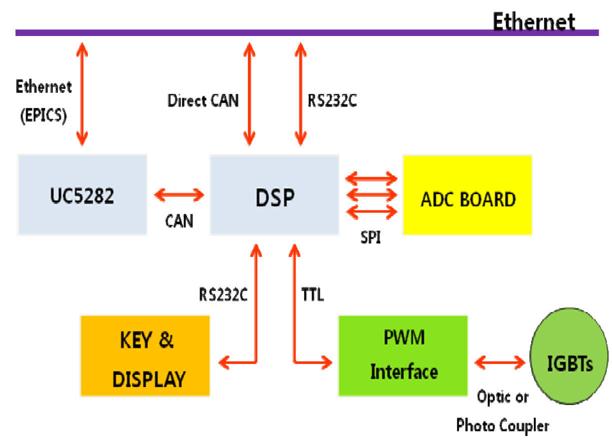

Figure 5: Developed Digital controller

Operating system for the UC5282 board use RTEMS-4.7 and control program is EPICS 3.14.9. The EPICES driver and device modules are programmed for CAN communication to DSP. IOC server was created by programmed modules. The MPS was controlled by Channel Access through the Ethernet.

The output current was measured using a zero flux current transducer and the sensed voltage was converted into a digital signal by the two AD977As analogue-to-digital converter (ADC) from Analog Devices. The outputs of both ADCs were averaged to increase the system stability. The switching frequency was 25 kHz. Thus the overall control loop was updated for every 40 µs using the timer interrupt of the DSP. Both key scan and the LCD display were carried out at the base routine not to interrupt PWM generation.

EXPERIMENTAL RESULTS

A 20 minute short term current stability was measured using the HP3458A digital voltmeter from Agilent Co, and the results are shown in Fig. 6. The stability of load current was less than 2 ppm at 2.5 A output current.

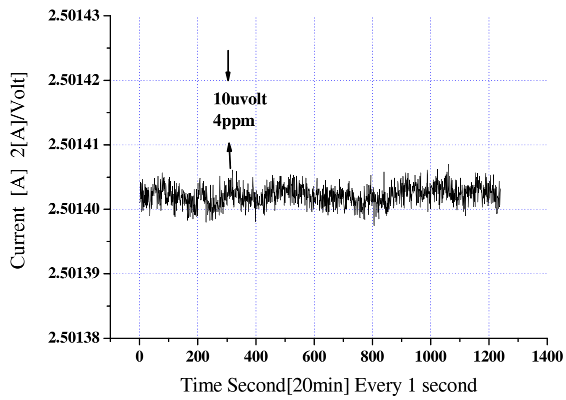

Figure 6: Current stability at load current of 2.5 A.

Fig 7 shows the step response of 0 to 5 A. Step response time is about 20 ms.

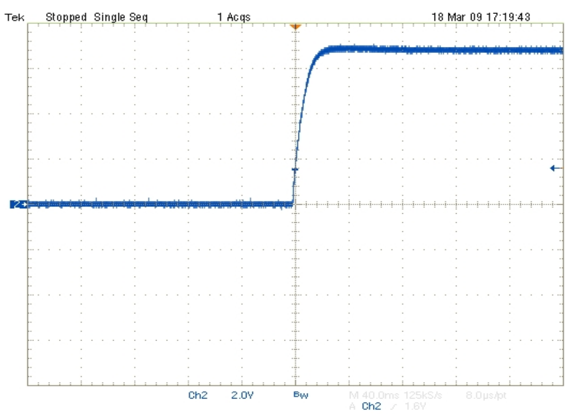

Figure 7: Step response of 0 to 5A (X-axis 40ms).

Fig 8 shows the current ramping test result. Ramping test is done from -2.5A to -7.5A. Each step is 0.1 A and 500 ms set time. It shows the good performance of iteration and accuracy.

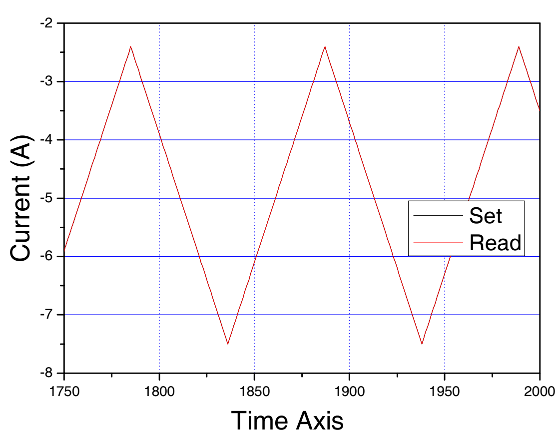

Figure 8: Current ramping test.

Fig 9 is expanded view of current difference between set and read value during ramping test. It shows the good controllability.

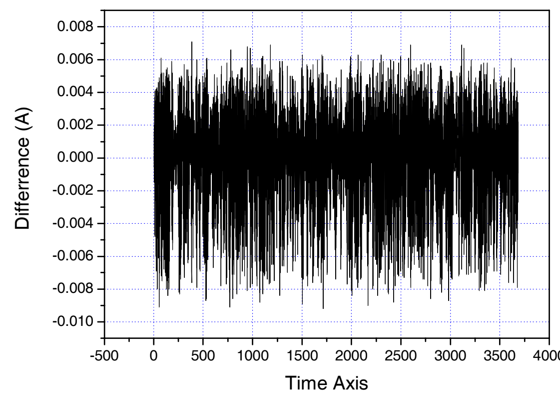

Figure 9: Current difference between set and read value.

CONCLUSIONS

This paper described the DSP-controlled bipolar power supply for the corrector magnet. The designed digital controller has two feedback loops for voltage and current which was updated every 40 µs. From the experimental results with fabricated power supply, high stability and high accuracy step control were achieved. The short term stability is about ~2 ppm. The rising time was about 20ms when step function from 0 to 5A was fed. And ramping test shows good results. The differences between set and read-back values when ramping test were small such as about ±8mA.

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