SLAC-PUB-12614
June 2007

ILC – ATF2 DC-MAGNET POWER SUPPLIES*

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Abstract

In 2008 KEK is commissioning ATF2 - an extension to the existing ATF. ATF2 is a mockup of the final focus test beam accelerator envisioned in the ILC. SLAC is designing the power supply systems for the dc magnets in the ATF2, which will require 38 power supplies ranging from 1.5 kW to 6 kW, and currents from 50 A to 200 A, all rated at output voltages not higher than 30 V. Because of the extensive quantities of magnets required for the ILC, high availability is paramount to its successful operation, so the power supply topology chosen for the ATF2 uses N+1 redundancy, with 50-A power modules to construct each power supply. These power modules are current-mode buck converters, which operate in parallel with each other and one redundant module. One bulk power supply provides off-the-line regulated dc input to a number of the power supply systems. Current stability requirements for the magnets range from 10 to 1000 ppm. A precision current transductor and a recently developed SLAC-built 20-bit Ethernet power supply controller will provide the current regulation required. In this paper we present the conceptual design, prototype results, and the status of the power supply systems for the ATF2.

INTRODUCTION

In 2008 KEK is commissioning ATF2 - an extension to its existing Accelerator Test Facility. ATF2 is a mockup of the final focus test beam accelerator envisioned in the International Linear Collider (ILC). Because of the extensive quantities of magnets required for the ILC, high availability is paramount to its successful operation, and the topology chosen for the ATF2's dc-magnet power supplies will provide invaluable reliability data for the ILC.

The Power Conversion Department (PCD) at SLAC was responsible for defining and evaluating dc-magnet power supply topologies for high availability for the ATF2. The topology chosen uses N+1 redundancy with 50-A power modules to construct each magnet power supply. Based on the satisfactory performance results from a prototype power supply system [1], the PCD worked on the procurement process for the entire ATF2 power supply system and will perform pre-installation testing, installation and commissioning. Installation of the power systems will begin early-2008.

This paper describes the preliminary test results on the prototype power supply system and the aspects of the power supply systems that will be installed for the ATF2. Table 1 summarizes the basic requirements of the ATF2's dc-magnet power supplies.

* This work was funded by Department of Energy under contract DE-AC02-76SF00515

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Table 1: ATF2's Dc-Magnet Power Supply Ratings.

Type	*Quantity*	*Volts*	*Amps*	*kW*
		Extraction		
Quadrupole	**8**	**30**	**150**	**4.5**
		Matching		
Quadrupole	**6**	**30**	**150**	**4.5**
		Final Focus		
Dipole	**3**	**30**	**200**	**6.0**
Quadrupole	**14**	**30**	**50**	**1.5**
Sextupole	**5**	**30**	**50**	**1.5**
Quadrupole	**1**	**30**	**100**	**3.0**
Quadrupole	**1**	**30**	**150**	**4.5**

MAGNET POWER SUPPLY SYSTEM

A magnet power supply system consists of three main components: bulk power supply, high-availability power supply and an Ethernet power supply controller. Refer to Figure 1 for a block diagram of a typical arrangement for the ATF2's power supply systems in a rack.

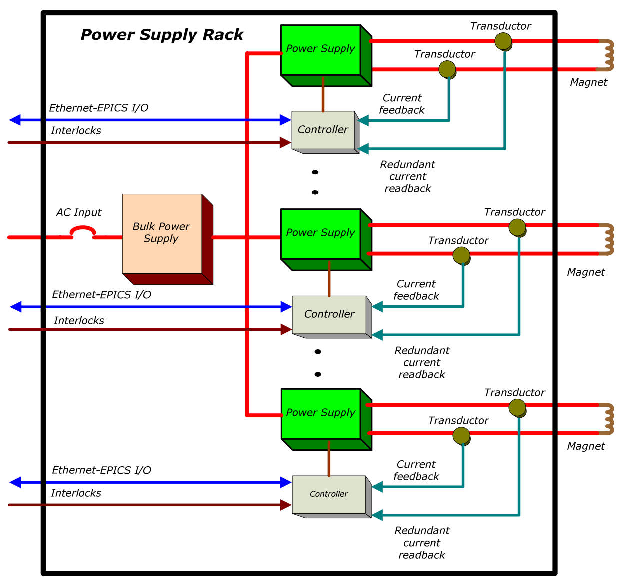

Figure 1: Block Diagram of Several Power Systems

Bulk Power Supply

The bulk power supply provides a stable (0.1%) fixed dc-voltage source to the high-availability power supplies, immune from AC line voltage variations. Its typical voltage control loop has a bandwidth higher than 1 kHz, high enough to compensate for most line and load changes. With the proposed topology, one bulk power supply can power several magnet power supplies. The bulk power supply does not require any special control.

Presented at Particle Accelerator Conference (PAC 07), 6/25/2007-6/29/2007, Albuquerque, NM, USA

A PLC interface to the bulk power supplies will provide remote on/off control and a soft-start ramp on the output voltage.

High Availability N+1 Power Supplies

Each magnet power supply is constructed from power modules that use a simple buck converter topology [2], rated at 30 V and 50 A. The power modules are arranged in an N+1 redundant configuration for increased availability.

In a power supply configuration that requires a 200-A output, four power modules will be used plus one redundant. In a situation where one power module fails, the remaining four modules will assume the load.

To ease maintenance and decrease spare parts, all power modules are identical. The power supply systems rated for 100 A to 200 A use a single crate each. Since a 50-A power supply system occupies less space; two of those systems share one single crate.

The power modules are easily replaced by being removable from the front. Hot-swapping features do not exist but may be necessary for the ILC.

Ethernet Power Supply Controller (EPSC)

The EPSC [3] closes the overall output current feedback loop of the power supply system. Taking the output current reading from a high-precision current transducer and an input reference set by the user, the controller's error amplifier adjusts the common analog reference signal sent to the power modules to maintain a highly-regulated output current.

In addition to the output current regulation, the EPSC also provides magnet and power supply interlocks. There are four available channels to use for external interlocks such as magnet thermal faults and water flow switch faults. It also reads in a ground current signal from the power supply to detect ground faults.

The EPSC provides control and readbacks via an Ethernet interface using a 32-bit Motorola Coldfire processor on a Netburner MOD 5282 board. The Netburner board also provides three UARTs, flash memory and a C complier. 24-bit Sigma-Delta ADCs provide the analog to digital conversion for readbacks. They provide an effective 20-bit resolution of 10 V full scale, taking 60 samples per second and have a stability of 2 ppm/°C. For the digital to analog conversion, a PWM circuit receives a 24-bit digital input from the remote computer to generate an 8-bit PWM signal. This signal passes through a fourth-order digital filter to provide an analog signal to the power supply.

PERFORMANCE

The following tests were conducted using a 30-V, 5-kW bulk power supply, four power modules for the power supply system, and a resistive load in series with a magnet load measuring 0.1 ohms and 3.3 mH, respectively. By using four power modules, this unit can produce up to 28 V and 150 A with one redundant power module.

Current Sharing

The output current is shared between power modules by giving them the same external current reference, which comes from the EPSC. The power modules have an internal current loop that tracks the external reference [2]. In the tests conducted, the modules shared current within 1%.

Figure 2 displays the differences in the module currents from the average and the stability of the individual internal current control under a total output current of 150A.

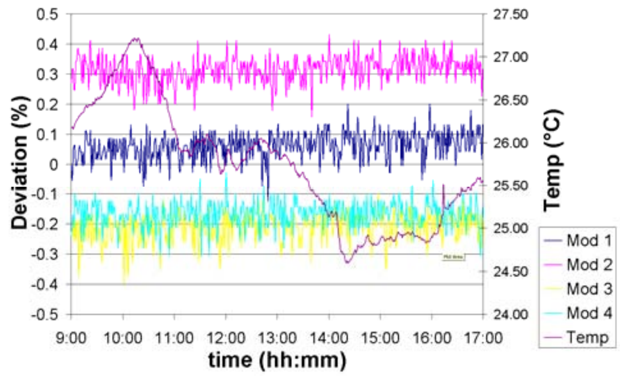

Figure 2: Current Sharing Deviation

Recovery

In the case when one power module fails, the remaining modules assume the remaining load. At the instant that a module is lost, the output current suffers a short transient: the output current drops by 6 A and recovers within 200 ms with no overshoot [4]. Since there is no overshoot, re-standardizing of the magnet is not required.

Figure 3 shows the transient response of the system when one module fails. When a second module fails, the power supply will automatically shut off.

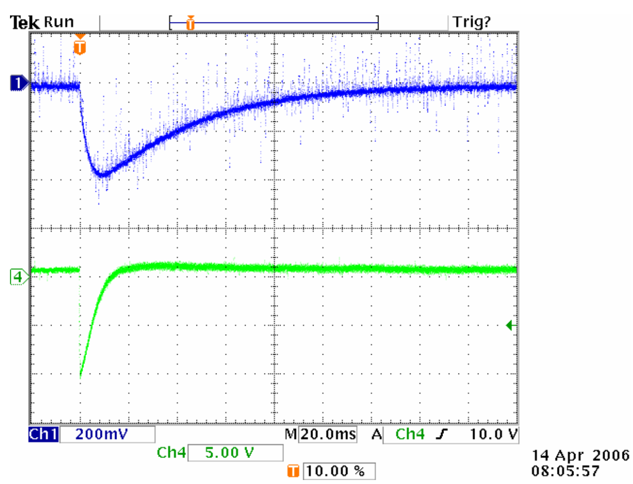

Figure 3: Current Recovery Response at 150-A Output
Ch 1: Output current 15 A/V; Ch 4: Output voltage

Using a Hall probe, magnetic measurements conducted by SLAC's Magnetic Measurements Department determined the effects of the current drop on the magnetic field. The magnetic field suffered a drop of about 100 Gauss when the output current drops by 6A. During this test, the current was set at 150 A and the nominal field was 3.1 kGauss [4]. Similar to the current, the magnetic field does not overshoot and returns to the previous nominal field, and thus will not require re-standardization. Figure 4 below shows the measurement of the magnetic field when a module fails.

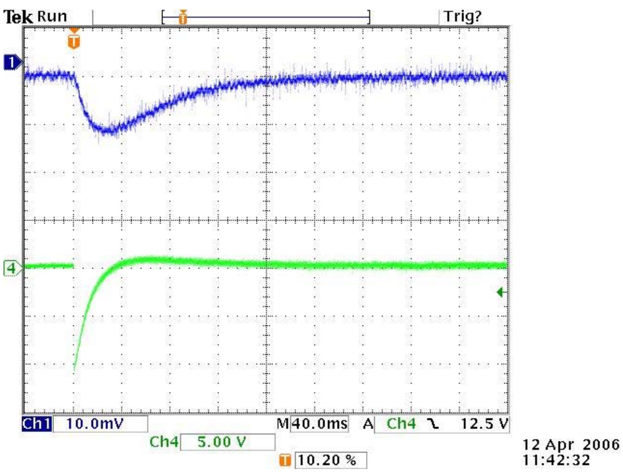

Figure 4: Magnetic Field Recovery Response at 150 A Ch 1: Magnetic Field 10 kG/V; Ch 2: Output Voltage

Stability

The short-term current stability, defined as 10 minutes, deviates 2 – 3 ppm from the mean value when looking at the total deviation. The RMS stability value, as defined above, is < 1ppm.

The long-term stability, defined as 8 hours, deviates 5 ppm when looking at the total deviation. The RMS value is 1ppm. The temperature change during this test was 2°C. The long-term deviation in current is then 2.5 ppm/°C. Figure 5 shows the normalized output current of the system over an 8-hour period.

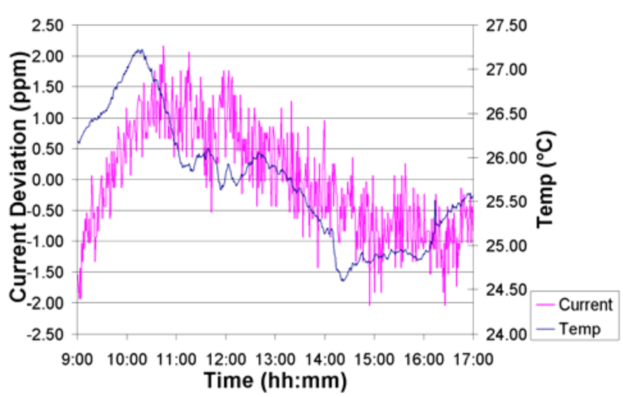

Figure 5: Current Stability and Temperature

Bandwidth

The error amplifier in the EPSC is tuned for a system frequency response bandwidth of 25Hz. The Bode plot in Figure 6 shows the -3dB point at 25Hz. Procedures to adjust this bandwidth are described in [5]

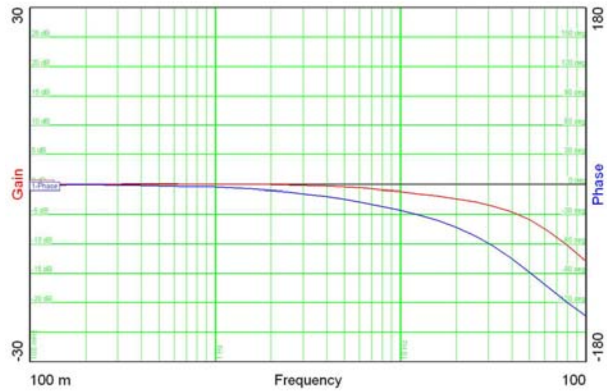

Figure 6: EPSC's Feedback Loop Frequency Response

CONCLUSIONS

The prototype power supply system provided test results that met or exceeded the performance requirements needed by the magnets for the ATF2. The performance of these power supplies will provide invaluable reliability data for the ILC. The Power Conversion Department at SLAC will be part of the international collaboration effort to design and commission the dc magnet power supplies for ATF2 at KEK.

ACKNOWLEDGEMENTS

The authors would like to thank Cherrill Spencer for her assistance during the design and specification of the magnets, and Achiem Weidmann for his support in analyzing the transitional magnetic field effects when a power module fails.

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