

A Multi-Channel Corrector Magnet Controller *

G. E. Leyh, A. R. Donaldson SLAC, Stanford CA 94309
L. T. Jackson LBL, Berkeley CA 94720

ABSTRACT

Approximately 1000 individual X-Y corrector magnets will be installed on the PEP-II rings, arcs, and injector lines. Each magnet will require a bi-polar current of up to 12 A, with a 24 hour stability of better than 0.1%. A 16 channel, modular power supply design has been developed to meet this requirement, with emphasis placed on reliability, repair time, and installed cost per channel. This design, which is based on a 6U Eurocard crate architecture, has 16 slots for individual drive modules, plus a 17th slot for crate diagnostics and interface to the control system. The crate is air cooled. Each drive module consists of an H-Bridge MOSFET switching array, input and output filter networks, two isolated precision current sensing elements (feedback and monitor), and an error amplifier, plus extensive fault detection and current limiting circuitry. Technical specifications, diagrams, and test results are presented.

INTRODUCTION

The PEP-II project will consist of two storage rings, each 2.2 km in circumference, plus an additional 4.6 km of extraction, bypass, and matching beam line sections. Approximately 1000 horizontal and vertical correction magnets will be utilized on these beam lines, with the maximum current requirements for each corrector magnet ranging from ± 6 to ± 12 Amperes. Control of these correctors will be distributed between two fundamentally different control systems; one will provide an analog command signal, the other will provide a serial digital command link.

A unified design architecture is desired for all of the corrector power supplies, in order to take advantage of the economies of scale and mass production, and to simplify documentation and maintenance procedures for the entire installation. A modular crate architecture has been chosen, in order to meet the needs of the various corrector topologies that will be encountered on the storage rings and linac.

A high emphasis will be placed on the total machine reliability, since the primary mission of the PEP-II facility is to become a "factory" for neutral B mesons. Therefore, the MTBF (Mean Time Between Failure) and the MTTR (Mean Time To Repair) are important underlying factors in the design of this corrector power supply system.

REQUIREMENTS

The overall performance requirements for each of the corrector drive modules are given as follows:

Input DC Bus Voltage	20 to 50 V
$I_{out, max}$ (programmable)	± 6 to ± 12 A
$P_{out, max}$ (per channel)	600 Watts
Ripple Current (DC to 50 kHz)	± 0.05 % of I_{max}
Stability	± 0.05 % of I_{max}
Reproducibility	± 0.1 % of I_{max}

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In addition, each power module must have:

- Internal protection against electrical faults
- An automatic thermal shutdown feature
- The ability to phase-lock its internal switching frequency to the 60 Hz mains
- A redundant readback of the output current
- Full "hot swap" capability

SYSTEM DESCRIPTION

A modular crate architecture is utilized in this design, in order to maximize the flexibility and serviceability of each installation. The physical crate is a standard 6U by 220 mm Eurocard format, available off-the-shelf from Schroff [1]. The crate has 17 slots, one for a control system interface card, and 16 slots for power conversion modules. Each power module has a 'personality card', which is mounted directly on to it. This personality card contains passive components that determine the maximum output current limit, the transfer function of command voltage to output current, and the compensation network for the error amplifier section. If a power module is replaced, the personality card is removed from the old module and installed on the new one. In this way, all of the operating parameters specific to the load will be in effect with the new module. All cards and modules are accessible from the front of the crate, and connect to the backplane using standard Eurocard connectors. Air cooling for the crate is provided by fan rack sets and plenums, also offered by Schroff, which draw in cool air from the aisle and pass it through the crate and into the rack, thus keeping the rack interior at positive pressure. A single hinged front cover provides access to the 16 power modules.

A simplified block diagram of the crate is presented in Figure 1. A unipolar bulk power supply provides the main DC power to the crate through a 180A Powerpole connector on the

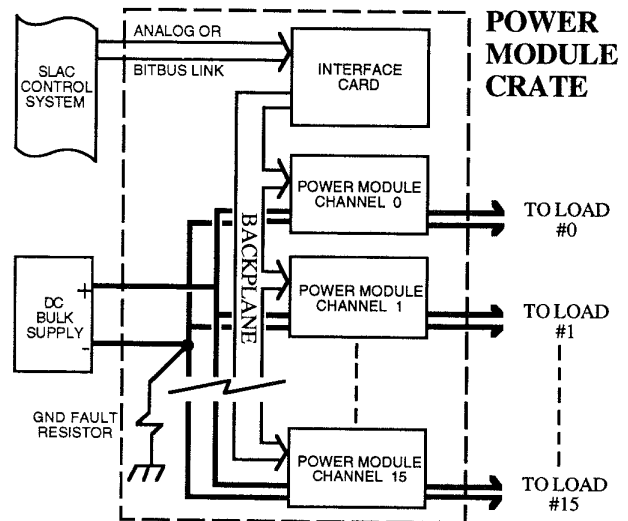


Figure 1.

rear panel. Command and synchronization signals are provided through the backplane by the interface card, which will be either analog or digital based, depending on the installation. The main DC power is distributed to the individual modules along with utility voltages and control signals also via the backplane. A standard 48 pin, type "E" DIN connector is used for all signal and power connections between each power module and the backplane. The interface card plugs into the same backplane, and uses the VME format for connector type, positioning, and module width. By using the card to backplane approach, all internal wiring has been eliminated, except for the 120 VAC power and the main DC power wires. All other external connections, including the outputs to the magnets, are accomplished through printed circuit mount connectors on the backplane, thus allowing the assembly work to be performed by outside board fabricators. Since the crate enclosures come pre-assembled from Schroff, the only in-house assembly work to be performed is to bolt on the backplane, front and rear panels, and insert 16 power modules and the appropriate interface card. The personality cards are then added to give each power module its own specific characteristics. A computerized test bench is used for testing the finished crate.

CONTROL

The installed corrector chassis will have to accommodate two fundamentally different types of control systems. The existing system utilizes a network of Multibus based computers, each of which controls a set of CAMAC crates. DAC modules in the CAMAC crates are used to generate 16 individual analog control signals, which are cabled in parallel to the corrector crate. These command signals are then piped straight through the interface card to the backplane. For the PEP-II rings, the control system will communicate directly with the power supplies, through a serial Bitbus[®] data link. The power supply will be responsible for performing its own digital-to-analog conversion, and supporting a digital interface with the control system. In the PEP-II scheme, the interface card will contain a DAC, multiplexed 16 channels wide, plus some logic glue and the Bitbus[®] specific support circuitry.

POWER MODULES

The function of each power module is to provide a regulated drive current to its respective load, in proportion to the command signal from the interface card. The power module also returns a redundant current signal to the interface card, as well as status and fault data. A functional diagram of the power module is shown in Figure 2. The command signal is received by a unity gain differential amplifier, whose purpose is to prevent ground loops, and to reject common-mode noise. The differential amplifier (Burr-Brown INA105) contains the laser-trimmed gain setting resistors, and as a complete unit exhibits a typical gain tolerance of 0.01% and a stability of 1 ppm/°C. The command signal is then compared against the current feedback signal by the error amplifier stage, which uses an OP-77 as the gain element. Compensation is provided by a single pole-zero network, which resides on the personality module. The resultant error signal is then sent to the input of a power servo amplifier module, also mounted on the PC board, which operates as a voltage amplifier with a gain of approximately 6, and has an effective rolloff frequency of about 2.5 kHz.

The servo amplifier used in this design is a commercial unit, the 30A8, manufactured by Advanced Motion Controls [2] for applications in robotics and process control. This model was chosen for its compact size, ruggedness, PC mount capability, and its internal fault protection system, which provides protection against thermal overload, and output short circuits (to either rail). A TTL fault signal is provided by the 30A8, which indicates the presence of a fault condition on the servo amplifier. This signal is applied to an external latch on the power module, which will shut down the servo amplifier if a fault condition persists for more than a few seconds.

The 30A8 produces unfiltered DC pulses from its H-bridge output stage, and must therefore be filtered appropriately before delivery to the load. The filter design employed is a variation of the classical Praeg filter [3], arranged to be symmetrical around power ground. The filter is set to be critically damped, and attenuates both the differential and common-mode components of the output ripple.

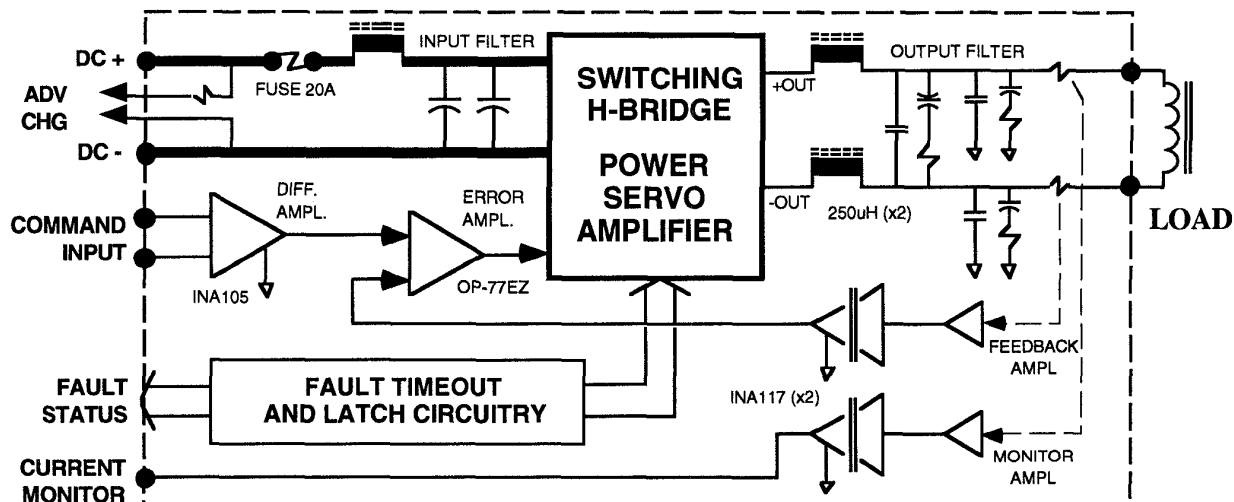


Figure 2. Power Module.

Following the filter are two precision 4-terminal Manganin shunt resistors, one in each output leg. These 10 milliohm shunts, which are made by Isabellenhütte, have a tolerance of 0.1%, and a measured stability of 13 ppm/°C, typical. The voltage developed by each shunt is amplified by an isolated amplifier, and referred to ground by a precision differential amplifier (Burr-Brown INA117). One shunt signal is fed back to the error amplifier, while the other is independently sent back to the interface card as a redundant current monitor signal.

The DC power input to the module is equipped with an LC filter network, which acts to decouple the switching noise of the servo amplifier from the DC mains. During a 'hot swap' operation however, the inrush currents that charge this DC input filter capacitor must be controlled, in order to prevent arcing damage to the DC power connection on the backplane. This is accomplished by a 2 pin auxiliary connector, which is set up to make initial contact with the DC on the backplane, and pre-charge the filter capacitor through a current limiting resistor before the main connector makes contact. This method eliminates the need for any pre-charge circuitry directly in the DC input circuit path, and thus improves the overall expected MTBF of the system.

MONITORING AND DIAGNOSTICS

In order to minimize the time required to make repairs, a crate diagnostics summary display is provided on the front of the interface card. This display indicates which module has experienced a fault, and if that fault condition is still present. There are also diagnostics for faults occurring on the crate, or in the bulk DC power supply. A crate fault will be indicated if the external interlock input to the crate is opened, or if excessive current is detected in a shunt resistor which connects the negative DC power busbar to the chassis ground. A module fault will be indicated if a given module experiences any one of the following fault conditions for more than a couple of seconds:

- A short circuit of either output lead to ground
- A heat sink temperature excursion in excess of 65°C
- An overvoltage or undervoltage of the DC power input
- An appreciable difference in currents on the output leads

Under the first three fault conditions listed above, the power module will protect itself by shutting down. The fourth fault condition is detected by a comparator circuit on the interface card that monitors the difference between the feedback and the monitor shunt signals on each channel. If the difference exceeds a preset value, a fault condition will be indicated for that channel, but the module will be allowed to continue operating, until the difference becomes large enough to trip the ground fault protection circuitry, either on the crate or in the module. When a module fault does occur, the technician at the site identifies the suspect module by looking at the diagnostic panel, and simply replaces it with a new one. A screwdriver is the only tool required to perform this replacement. If the problem still persists, then the cause is probably in the cable plant or at the load, since all of the electrical components for that channel, including the output filters, are on the module. Test points for the input and output voltages are available on the front panel in order to verify proper crate operation.

TEST RESULTS

A prototype power module has been constructed, and has been extensively tested in an environmental chamber, under a variety of conditions. Presented here are the measured performance specifications of the completed power module:

TEST CONDITIONS (unless otherwise noted)

DC Mains Voltage	40 Volts
Maximum current limit	12 Amperes
Load Impedance	5 Ohms + 6 mH
Switching Frequency	30 kHz
Temperature Range	15 to 65°C

SPECIFICATIONS:

Initial Offset Error	480 uA
Transfer Function	1.000 V = 2.000 A
vs. temperature 10-50°C	13 ppm/°C
non-linearity	0.025%
repeatability, card-to-card	±0.1%
Small Signal Bandwidth	
3dB, for 60 mA signal	1.5 kHz
Slew Rate (70 V mains)	2500 A/sec
Step Response (5 A step)	12 mS
RMS Output Current Noise	
DC to 200 kHz (0 A)	0.01% of FS
DC to 200 kHz (12 A)	0.01% of FS
RMS Common-Mode Noise	120 mV
RMS Noise injected back into DC Busbar	20 mV
Power Dissipation (at 12 A)	19 Watts
Output Short Circuit Duration	
Line-to-Line	CONTINUOUS
Line-to-Ground	2 sec (Unit shuts down)

REFERENCES

- [1] Schroff Inc., Warwick RI.
- [2] Advanced Motion Controls, Camarillo CA.
- [3] W. F. Praeg, "A high-current low pass filter for magnet power supplies," *IEEE Trans. Industrial Electronics and Control Instrumentation*, Vol. IECI-17, No.1, pp. 16-22, Feb. 1970