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A 20 AMPERE SHUNT REGULATOR FOR CONTROLLING INDIVIDUAL MAGNETS IN A SERIESED STRING

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At the CEBAF accelerator, groups of dipole magnets are often connected together in series and powered from a single large constant-current regulated DC supply, referred to locally as a "box" supply. Besides the economy realized, this configuration promotes correct field tracking of all elements of a beam transport channel. However, it is often desirable to vary the current in one element of a string independently of the others, particularly at the entrance and exits of transport channels. A 20 ampere programmable current shunt is described. Installed in parallel with the desired magnet, it permits shunting (bypassing) up to 5% of the string current around that magnet.

The shunt regulator consists of a bank of MOSFET power transistors operated in linear mode. Regulation of current through the passbank is obtained by feedback from a manganin shunt maintained at a constant temperature for stability. The module is designed for remote operation and provides readbacks of various parameters useful for maintenance. To achieve complete electrical isolation, an onboard microprocessor provides remote communications via an opto-isolated serial data link. Constructional details and initial operating experience with the plug-in shunt are described.

I. INTRODUCTION

A prototype 20 Ampere Shunt Regulator was initially described[1]. This paper reports on the implementation and operating results of the production units derived from that prototype. Over one hundred shunt regulator modules have now been installed at CEBAF and are currently operational.

For purposes of economy and convenience in energy tracking, the CEBAF accelerator places up to 40 bending magnets in a series-connected string. Selected magnets in the string are equipped with shunt regulators, which can bypass up to 5% of full power supply current through that magnet, thus providing a measure of individual adjustment. The shunts use paralleled power MOSFET devices as the pass elements. The current through the passbank is sensed by a precision shunt resistor and linear feedback is used to control the output. Each shunt must be individually programmable & monitored from control room, be electrically and mechanically robust, and for maintenance purposes must be able to be quickly exchanged. These objectives were successfully achieved with the compact 400 watt plug-in module described.

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II. DESIGN APPROACH

The module shunts current around the magnet by varying conduction through a passbank of eight parallel power MOSFET transistors. Each MOSFET stage is contained in an independent local current-feedback loop to insure each parallel stage presents equal gain and load sharing characteristics to the overall feedback loop (See Figure 1). This configuration must be protected against any failure which would cause the stage to "hog" excess current, typically the shorting of the MOSFET junction. Should this occur, a signalling fuse located in series with the MOSFET source lead clears and the blown fuse is reported to the processor. Load current is re-distributed equally amongst the remaining stages. An important characteristic of the chosen topology is that, with the MOSFET's gate-source voltage reduced to zero, it presents a very high impedance. Thus, turning off the control power to the module simply results in zero current flow through the module; a fail-safe mode.

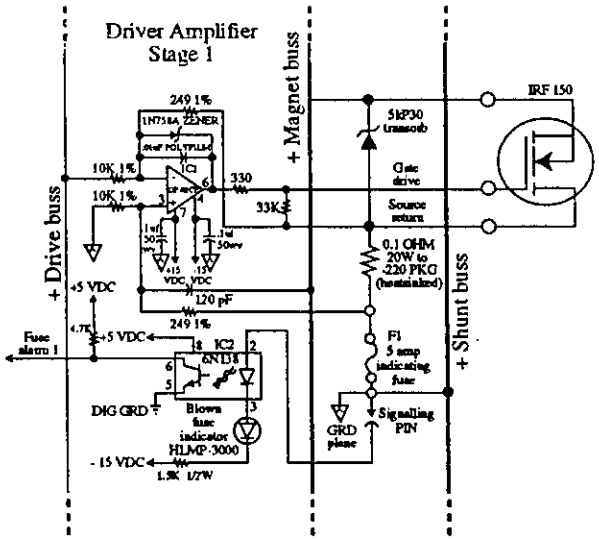

Figure 1: Detailed circuitry of single MOSFET drive stage.

The eight stages are paralleled across the output buss and driven from a common controller amplifier. This amplifier compares signals from a common current measuring shunt and a DAC reference and drives the output stages to achieve constant current regulation of the entire module current (Figure 2).

V. DETAILS OF CARDCAGE CONSTRUCTION

The shunt modules are designed to slide into a cardcage-style chassis, making electrical connection by means of a connector mounted on the rear apron of the heatsink. Since the shunt is directly connected to a magnet string with potentials as high as 600 VDC above Earth Ground, safety considerations require that the module be totally enclosed in a chassis whose covers are interlocked to the dipole string power supply.

Unlike a conventional power supply, for the shunt module the hazardous source of power is the box power supply. At CEBAF, the shunt cardcages are often located in entirely different buildings than the box supplies. For this reason, it is necessary to completely interlock the shunt modules and cardcage to that box supply. Removable front and rear chassis covers are interlocked to the box supply to prevent personnel access to the shunt module while the magnet string is energized. Heatsink overtemperature or loss of more than two driver stage fuses will also trip off the box supply.

For safety purposes and ease of interlocking to the box supply, only shunts connected to a common magnet string are housed together in a common chassis. To suit the CEBAF applications, two cardcage packages were developed, a single-channel and a four-channel unit.

In the single-channel chassis, the shunt module slides in horizontally on insulated card guides. Because airflow through the rack is in a vertical sense, an integral linear squirrel-cage fan is employed to force air across the heatsink fins. An integral airflow sensor is interlocked to the box supply to remove power should this fan fail. In the four-channel unit, the modules mount vertically, and air flows directly over the heatsink fins from vents strategically located in the top and bottom chassis covers.

VI. INITIAL OPERATING RESULTS

From an operational standpoint, the shunts have worked as desired. No unusual or undesirable modes of operation have been experienced. A single module design has sufficed for all applications to date. Field repair of a failed module is accomplished by remove-and-replace, requiring only a few minutes to restore service to a faulted channel. Remote programming and readback, via the RS-485 link, has worked without problem-validating the strategy of using the same microprocessor circuitry and software as the time-proven trim cards[3].

There are presently 112 shunt regulators installed and operational at CEBAF. Typically, one module shunts one magnet, however there are eight applications where a module shunts two adjacent magnets in a string. There are 34 four-channel chassis and 11 single-channel chassis installed.

In the past three and one half months, we have accumulated a total of 150,000 module-hours of operation [4]. Six failures have been experienced. These failures were all traceable to workmanship errors in the initial manufacture (pinched wires, poor solder connections, etc.).

VI. REFERENCES

[1] E. Martin, et al., "Re Use of Common Elements of a Corrector Power Supply Design to Develop A Dissipative Shunt Regulator Design," E. Martin, et al., Conference Record of 1992 IEEE Nuclear Science Symposium, October 25-31, Vol. 1, p. 563-565.

[2] N. Dobeck, "Precision Power Supply Control Module," Conference Record of the 1991 IEEE Particle Accelerator Conference, May 6-9, Vol. 2, p. 935-937, IEEE91Ch3038-7.

[3] N. Dobeck, et al., "Precision 32 Channel Power Supply System," Proceedings of the 1990 Linear Accelerator Conference, September 10-14, p. 490-492, LANL LA-12004-C.

[4] W. Merz, et al., "Early Operations and Reliability Experience With the CEBAF DC Magnet Power Supplies," to be published in Proceedings of the 1995 IEEE Particle Accelerator Conference.