OVERVIEW OF THE AGS COLD SNAKE POWER SUPPLIES AND THE NEW RHIC SEXTUPOLE POWER SUPPLIES*

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Abstract

The two rings in the Relativistic Heavy Ion Collider (RHIC) were originally constructed with 24 sextupole power supplies, 12 for each ring. Before the start of Run 7, 24 new sextupole power supplies were installed, 12 for each ring. Individual sextupole power supplies are now each connected to six sextupole magnets. A superconducting snake magnet and power supplies were installed in the Alternating Gradient Synchrotron (AGS) and commissioned during RHIC Run 5, and used operationally in RHIC Run 6. The power supply technology, connections, control systems and interfacing with the Quench Protection system for both these systems will be presented.

AGS COLD SNAKE POWER SUPPLIES

Power Supplies Description

There are four power supplies (p.s.'s) used in the AGS cold snake p.s. system. These are all current regulated power supplies with a DCCT current sensing element.

The Solenoid p.s. is rated at 15Volts and 440Amps dc. The ac input to the Solenoid p.s. is 208Vac. The Helical p.s. is rated at 50Volts and 400Amps dc. The ac input to the Helical p.s. is 480Vac. The Solenoid and Helical p.s.'s are commercially available voltage regulated switchmode p.s.'s which are used within the BNL designed current regulator. The required p.s. current reproducibility is 0.01% of maximum current.

The 2 bipolar trim p.s.'s are 20Volts and 50Amps dc. The ac input to the bipolar trim p.s.'s is 208VAc. These are the same bipolar p.s.'s that are used for the RHIC corrector magnets. The bipolar p.s.'s are also current regulated DC p.s.'s with an inner voltage loop. In addition, the bipolar p.s.'s utilize a tracking voltage loop to control the DC output of a switchmode DC-DC converter. The DC-DC Converter thus acts as a Pre-Regulator for the H-bridge MOSFET Output Power Stage. The voltage across the MOSFET Output Power Stage is kept low by the tracking voltage loop to reduce the power dissipation across these MOSFETS. Two of the MOSFETS (upper) act linearly while the other two MOSFETS (lower) act like a switch controlling which direction the current flows through the magnet load. The required p.s. current reproducibility for the trim p.s.'s is 0.1% of maximum current.

During normal operation these p.s.'s ramp up slowly to a dc level and then they stay there.

* Work supported by Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy
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The Solenoid p.s. and Helical p.s. are both connected to their own quench protection assemblies (qpa's). These qpa's contain an energy extraction resistor across an IGBT switch as well as a crowbar circuit. The IGBT and energy extraction resistor are connected to the positive output terminal of the p.s. and the magnet. The crowbar is connected across the dc terminals of the p.s. When a fault occurs n the p.s. or the qpa or if the magnet quenches, the crowbar shorts out the p.s. and the IGBT opens so the energy extraction resistor is now in series with the load. The current from the load goes through the crowbar SCR and through the energy extraction resistor. The supply also trips to the STANDBY-FAULT state. The trim p.s.'s don't have a separate qpa, they have a crowbar with an energy extraction resistor built into them.

There is a quench detector for the AGS cold snake p.s. system which monitors the voltage across the magnets and the current of the magnets. The quench detector trips the p.s. to STANDBY-FAULT if a quench is detected. When ever the p.s. trips to the STANDBY-FAULT state the energy extraction resistor becomes part of the circuit because the IGBT switch across it opens up and the crowbar fires.

AGS Cold Snake P.S. Magnet Loads

There are 4 superconducting magnets in one cryostat. Each magnet is connected to one p.s. The magnets are called the Solenoid, the Helical and the 2 trims. The Solenoid and Helical magnets are connected at one point while the trims are independent. The Helical magnet has an inductance of 7H. The Solenoid has an inductance of 70mH. The trim magnets are 25mH each. The dc resistance of the cables to the magnets is about 5mohms. The Helical magnet is connected to the 50Volt/400Amp p.s. The Solenoid magnet is connected to the 15Volt/440A p.s. The two trim magnets are each powered by a bipolar 20Volt/50Amp p.s.

NEW SEXTUPOLE POWER SUPPLIES

Original Configuration vs. New Configuration

In the original configuration there were 24 sextupole p.s.'s in RHIC. Twelve p.s.'s in the blue ring and twelve p.s.'s in the yellow ring. Each sextupole p.s. was connected across 12 sextupole magnets. The sextupole magnets are all superconducting magnets in RHIC. Each sextupole magnet has an inductance of about 0.83H. A sextupole p.s. in this configuration would see a total of about 10H with a dc cable resistance of about 0.42 ohms.

In order to achieve higher order chromaticity control a string of 12 sextupole magnets connected to one sextupole p.s. was split in half. Now one sextupole p.s. would be

connected to half the string and the new sextupole p.s. would be connected to the other half of the sextupole string. This doubles the total number of sextupole p.s.'s from 24 to 48. For the new configuration, this means there are 24 sextupole p.s.'s in the blue ring and 24 sextupole p.s.'s in the yellow ring. The inductance each of the sextupole p.s.'s see now is 4.8H and the resistance is still about 0.42ohms. All of the sextupole p.s.'s are located in the alcoves.

Power Supplies Description

The original sextupole p.s.'s are current regulated DC p.s.'s with an inner voltage loop. In addition to this inner voltage loop these sextupole p.s.'s have a linear MOSFET output stage with a 12 pulse SCR Pre-Regulator. These p.s.'s use a DCCT as the current sensing element. The required p.s. current reproducibility is 0.025% of maximum current rating. The p.s. maximum ratings are 100Volts at 100Amps. The AC input is 3 phase 480V at approximately 14 Amps maximum. The maximum voltage ripple is 0.2Vpp in the 100% tap setting. The p.s.'s have a 70V tap setting as well.

The new sextupole p.s.'s are commercially available voltage regulated switchmode p.s.'s which are used within the BNL designed current regulator. These p.s.'s are rated at 33Volts and 33Amps dc. The ac input to these p.s.'s is 110Volts ac and about 15Amps ac.

The original and the new sextupole p.s.'s each have a qpa which operates in a similar way to what was described for the qpa used in the AGS cold snake power supplies. There are 2 differences with the new sextupole qpa's. A contactor was added for remote ON/OFF control of the commercial p.s. A DCCT was also installed in the qpa for the regulation of the new sextupole p.s. There is one quench detector in each of the 6 alcoves for the sextupole p.s./magnets which operates like the quench detector described in the AGS cold snake p.s. system section. One quench detector in each alcove monitors 8 p.s.'s. Each p.s. is connected to six sextupole magnets.

CONTROL SYSTEM

AGS Cold Snake P.S. Control System

The Helical and Solenoid p.s.'s use the same 3u chassis control bucket. See Figure 1. In this control bucket resides the setpoint card, the current regulator card, the buffer card, , the DC Overcurrent (DCOC) card, the digital isolation card and the control card. The setpoint card receives a 0-10V analog signal from a fiber optic interface card which resides in another bucket.. This analog setpoint is sent over the 3u control chassis backplane to the BNL designed current regulator card. This current regulator card has a removable PC board for adjusting time constants to stabilize the p.s. current loop. The buffer card sends four analog signals back to the Multiplexed Analog to Digital Converter (MADC). These four signals are p.s. current setpoint, output current, output voltage and p.s. current error. The DCCT resides in the QPA and the DCCT electronics card was purchased from an outside vendor. The DCOC card receives the shunt input from the commercial p.s. shunt and uses this shunt in a DCOC circuit on the DCOC card. The digital isolation card receives commands from a Node card which is external to the p.s. and sends p.s. statuses back to this Node card. The Node card communicates over a MODBUS Plus network to a MODICON Programmable Logic Controller (PLC). This PLC communicates with the front end VME computer over an Ethernet connection. A NODE card is an inexpensive multichannel I/O device designed at BNL which receives commands from the PLC and distributes these commands out to as many as 12 p.s.'s. The p.s. statuses are also sent back to the NODE card and then onto the PLC from the NODE card. The control card controls which state the p.s. is in and monitors the p.s. faults and trips the p.s. to a fault state if a fault occurs. This control card employs a microprocessor to control the

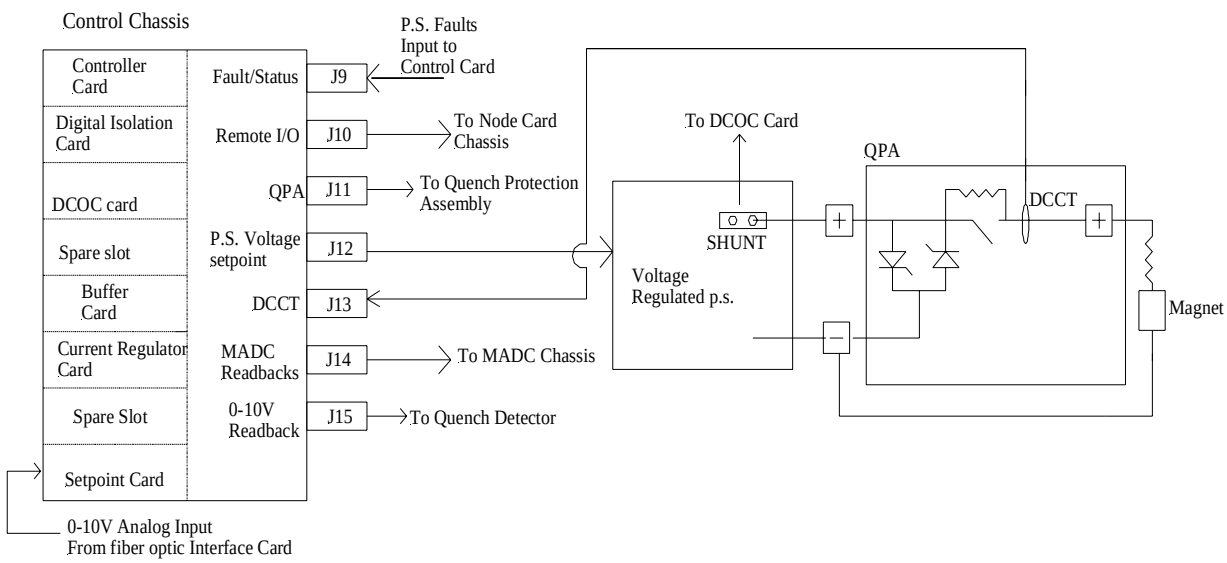

Figure 1 AGS Cold Snake (Helical and Solenoid) and New Sextupole Block Diagram

p.s.. The p.s.'s must also interface with the quench protection system. There are connections made to the Quench Protection Assembly (QPA) and the Quench Detector. The p.s. sends the p.s. status to the QPA and any QPA faults are sent back to the p.s. as well. The p.s. output current is also sent to the Quench Detector using a 0-10V readback.

There is a separate AC compartment for the Helical and Solenoid p.s.'s that is used to remotely turn the p.s.'s ON and OFF. It also contains 110VAC which is used to power the low level housekeeping p.s. in the 3u control chassis.

The trim p.s.'s do not have a 3u control chassis. The p.s. has the equivalent of the 3u control chassis built into the p.s. itself.

New Sextupole P.S. Control System

The New sextupole p.s. control system is very similar to the AGS p.s. control system except that the QPA includes the AC compartment in the QPA in order to save space.

OPERATING PARAMETERS

The AGS cold snake p.s. system p.s.'s operate at the following current levels in run 7:

- The Solenoid operating current is 212 amps dc.
- The Helical operating current is 282 amps dc.
- Trim 1 p.s. operating current is 0 amps dc.
- Trim 2 p.s. operating current is 7 amps dc.

The Helical p.s. can ramp up at a maximum rate of 1Amp/sec. The Solenoid p.s. can ramp up at a maximum rate of 3Amps/sec. The Trim 1 and Trim 2 p.s.'s can ramp at a maximum rate of 3Amps/sec.

The new and old sextupole designed currents at store are listed below by family name for the blue ring:

- B-sxf-mi = 8.44 amps dc
- B-sxd-mi = -32.35 amps dc
- B-sxf-po = 22.42 amps dc
- B-sxd-mo = -30.94 amps dc
- B-sxf-pi = 14.78 amps dc
- B-sxd-ps = -11.94
- B-sxf-mo = 0.883 amps dc
- B-sxd-po = -13.04 amps dc

The sextupole p.s. can ramp at a maximum ramp rate of 0.2Amps/sec.

OPERATIONAL EXPERIENCE

The AGS cold snake p.s.'s and the new sextupole p.s.'s have been very reliable. When the reliability of these two systems are compared with some of the custom made p.s.'s in RHIC one can see a dramatic difference. The commercial supplies used in both of these power supply systems have been in the industry for many years and they usually come with 5 year warranties. There have been 2 problems with the new sextupole ps system in Run 7, which is the first run they have been used in. The first problem was a shorted bypass capacitor on the buffer card which is in the BNL built 3u control chassis. The other problem was a problem with the way a D connector was constructed on the back of the 3u control chassis.

The AGS cold snake p.s.'s have had a few more problems which are not with the p.s.'s but once again with the equipment around the p.s. The node card for this system had a problem after a power dip so the ac power had to be re-cycled to the node card to fix it. The node cad has been placed on a UPS. There were some instances when the Helical p.s. tripped on an error fault. This was because the operator ramped at the wrong ramp rate sometimes or because the magnets were not ramped in the correct order. Since then a program which automates the ramp up procedure is being used so these mistakes cannot happen again. There were some spontaneous OFF trips of the Helical p.s. which was caused by a problem in the 3u control chassis. The 3u control chassis was opened up and connections were tightened to fix this problem. The commercial p.s.'s have had no problems. There have also been qpa fan switch faults which were a function of the wrong switch being used and the fan switch getting dirty increasing the contact resistance. This is being fixed during the summer shutdown of 2007 by using the correct switch and a circuit which will not let a fan fault occur unless the resistance of the switch is at least 25kohms.

ACKNOWLEDGEMENTS

The authors would like to thank the technician's in the Collider Electrical p.s. group who work very hard on these p.s.'s. They are Joe Drozd, Rich Conte, Fred Orsatti, Tom Nolan, Jeff Wilke, Jim Osterlund, Ron Zapasek, Rich Kurz, Gregg Heppner, Mitch Delavergne Brian Karpin, Dan Oldham and Joe Gormley.

This work was supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy and by a sponsored research grant from Renaissance Technologies Corporation. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

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