POWER SYSTEMS FOR THE RHIC FIRST SEXTANT TEST [1]

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Abstract

The first sextant test of the RHIC project is an opportunity to evaluate the many systems that must work together for the accelerator to operate. For the main dipole string, the actual main quadrupole power supply with its DSP regulator and output circuit compartment will be used. Temporary supplies will be used for the main quadrupole string, quadrupole offset, and quadrupole shunt supplies. This will let us both measure the performance of the main supply as well as determine the interaction among other power elements in the circuit. Correction elements will also be powered. The actual gamma-T power supplies will be used, as well as temporary supplies for the dipole correctors and sextupole supplies. Some of these units are required for beam to be transported, others are to be operated without beam to measure their performance, and how they interact with their superconducting loads. The power supply equipment, and that of other systems, required an infrastucture of AC power and output cable distribution in the RHIC tunnel, outlying service buildings, and interconnecting the tunnel to the service buildings. This note will describe the performance of the RHIC power supply systems during the sextant test, and the experience gained from this exercise.

1 MAIN POWER SUPPLIES

Each of the main power supplies consists of a single regulator controlling two power modules. The "ramp" power module has a high output voltage and is used to ramp the current from injection level to storage level. The "flattop" power module has a lower output voltage and is used to maintain the current at fixed levels. When the commanded current slope exceeds 10 Amps/sec the regulator automatically switches from the flattop to the ramp power module, this is referred to as "cross-over".

The regulator uses digital firing boards to time the firing pulses to the SCRs. Loop compensation and real-time sub-harmonic correction of the output voltage are carried out by a digital signal processor (DSP). The DSP calculates a firing count that is sent to the firing board at a 720 Hz rate. Twelve correction counts, one for each SCR pair, are calculated and sent to the firing board at a 3 Hz rate. The firing board adds the appropriate correction to the firing count and uses this adjusted value to fire the SCR pairs.

The sextant test provided an opportunity to test the stabilty, cross-over, and sub-harmonic correction capabilities of the power supplies on a load approximating that of the main quadrupole string.

The regulator used during the sextant test was a prototype. The digital boards had been fabricated as printed circuit boards, but the analog signal conditioner boards used were the prototype boards. The final regulator will be housed in a temperature controlled enclosure, this was not available for the sextant test.

1.1 Stability

The stability of the prototype power supply was measured using Hewlett Packard 3458 DVMs. Data was collected at a 60 Hz rate over a period of three hours. The short term stability was 3 ppMrms, this should be improved by the analog printed circuit boards. The long term stability was 20 ppM. This was dominated by the ambient temperature change, the temperature controlled enclosure will significantly reduce this drift.

1.2 Cross-over

The regulator contains two firing boards, one dedicated to each of the power modules. The firing board's outputs are gated; enabling the DSP to select the power module that will be active. When the DSP detects the current slope threshold is crossed it turns on the power module that will supply the current, it then turns off the power module that had been supplying the current. This process is timed to occur between the SCR firings. The voltage loop is not broken during the cross-over, only a scaling factor in the voltage-to-phase angle conversion is altered. The maximum error during cross-over was measured and found to be 40 ppM. Adjusting the scaling factors in the voltage-to-phase angle conversion will reduce this error. In addition, adjustments to the power modules fault detection circuits were found to be necessary to accommodate the cross-over.

1.3 Sub-Harmonic Correction

Sub-harmonic correction was measured during the sextant test. The degree of sub-harmonic reduction vs. frequency is depicted in the table. Better reduction was achieved in the middle of the frequencies of interest. The reason for this is still being investigated. The sub-harmonic correction algorithm was coded in "C", coding the algorithm in the DSP's assembly language will increase the correction rate.

Sub-Harmonic Correction Acheived

Frequency (Hz)	Power Reduction (dB)
60	-1.09
120	-19.64
180	-15.08
240	-19.72
300	-1.13

2 GAMMA-T POWER SUPPLY

RHIC needs a Gamma-T jump to move rapidly through transition. This will be accomplished by pulsing the series connected quadrupole windings in the magnet corrector package. The current in this circuit will be allowed to rise to a planned operating value just prior to the “jump” and then forced to a negative value in a specified amount of time. During the sextant test the string of CQ6 and CQ8 series connected quadrupole magnets in alcove A were pulsed. The current in this quadrupole winding was ramped up slowly to a value of +40 amps. The current was then forced to transition from +40 amps to a value of -40 amps in 0.06 seconds. The parameters are shown below.

Gamma-T jump parameters

ITEM	DESIGN VALUE
Jump Current	+40 A to -40 A
Jump Time	0.06 seconds
dI/dT during jump	1333 A/sec

The core of the Gamma-T power supply was a 3 Kwatt (55A at 55V) unipolar switcher which was used to ramp the current in the magnet to 40 amps. At the initiation of the jump the switcher was disconnected from the 58 millihenry quadrupole magnet using MOSFET switches. The magnet was then allowed to resonate in parallel with a 6278uF capacitor for 60msec. The resonant frequency of this parallel LC circuit is 52.4 rad/sec (period 0.12 sec). Therefore, after 0.06 seconds the current in the magnet was forced to -40 amps and this allowed the switcher to be reversed and catch the magnet current at this negative value.

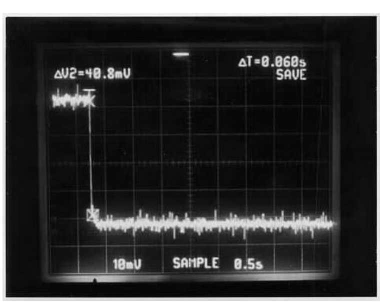

Figure 1 Current Reversal in Gamma-T Magnet

3 OUTPUT CIRCUIT COMPARTMENT

The output circuit compartment (10'x8'x9'H) contains the passive ripple filter, two pole DC contactor, two pole DC thyristor switches, DCCT head and regulator.

The frame of the compartment is made of AMCO aluminum structural framing system. The air-core inductor and DC contactor are mounted directly on the concrete floor. All the devices are natural convection except the DC thyristor switch main heatsink assembly which uses forced air cooling. In order to break the magnet flux path of the air-core inductor, magnet breaks are provided for the frame and roof surrounding the air-core inductor. In order to maintain the inductance of the air-core inductor nonmagnetic material are used at the vicinity of the air-core inductor. The housing of the ripple filter capacitor is stainless steel. The proper distance from the DCCT head to the air-core inductor is also maintained so that the stray flux does not exceed the manufacturer’s limit.

The 100 micro-H 5500ADC air-core inductor made by NEELTRAN consists of two half coils with total DC resistance of 197 micro-Ohms at 26 degree C temperature. The total weight is 5000 lbs. Proper air ducts between the layers of the coil windings are used to ensure that the maximum winding temperature is not exceeded. The filter capacitor made by CSI Technologies consists of 11 units of 6333 micro-F capacitors. The two-pole 6000A DC contactor with mechanical latching device is made by MICROELETTRICA SCIENTIFICA in Italy, the total resistance between the main terminals per pole is 8.6 micro-Ohms at 6000A and the contact resistance is 1.72 micro-Ohms at 6000A.

3.1 Design of the Output Switching Circuit for the Main Power Supplies

The ramp and flattop power modules share the same output circuit switches. The switches include the main SCR switches at the two legs of the outputs, the two pole electrical-mechanical contactor, and the free-wheel circuit self-triggering SCRs. The main SCR switches include the associated Pulse-forming-network turn-off SCRs. The two pole switch design isolates the main power supply from the magnet string so that the transient during operation does not propagate to the power supply. For example , the return circuit to ground voltage would rise to 512V when the free-wheel circuit is activated. The two pole design also reduces the voltage stress of the switching devices. The switches work with the main power supplies, if there is a high current fault or quench fault the power supplies will turn off and the main switches will open. DC ground fault monitoring will be installed to monitor the whole magnet string. The system will be grounded at both legs by the high impedance sensing network of the ground fault monitoring relay.

The main SCR switches serve two main purposes. They lengthen the life of the electrical-mechanical contactor. During normal operation the SCR switch makes and breaks the current, therefore the contactor switches without a load. The SCR switch also turns off faster than contactor, it takes about 300 µs to interrupt the current while the contactor requires 20 ms to open.

When the SCR switch or contactor opens, the magnet current continues to flow, first it reverses the ripple filter capacitor voltage and then activates the self-triggering circuit of the free-wheel circuit SCRs. The energy stored in the magnet is then disspated in the energy dump resistors in the free-wheeling circuit. Because the time constant of the energy dump circuit is about 10 seconds, the speed of the main SCR switch is not important. Without the ripple filter capacitor, the voltage would rise so fast that it would exceed the system maximum allowable voltage before the self-triggering circuit and free-wheeling circuit SCRs conduct.

The main power supplies are capable of operating in invert mode, to avoid activating the free wheel circuit during invert the free-wheeling circuit firing voltage should be higher than the maximum system invert voltage. This is done by properly selecting the self-triggering circuit breakover voltages.

The main switch consistes of 6 SCRs in parallel; each SCR is in series with two paralleled stainless steel resistors.

The 1.3 milliohm resistor is used to force balanced current sharing between the SCRs, and to support the minimum anode to cathode turn on voltage. The SCRs were selected so that conduction voltage (about 1.2 V) is within 70 mV range for static current sharing. An SCR conducting monitoring circuit is provided to detect over-current of any single SCR.

4 POWER SUPPLY CONTROL SYSTEM

The power supply control system consists of two distinct paths. The setpoints are provided by waveform generators and are sent in digital serial format over fiber optic cables. Discrete control and status is provided by Programmable Logic Controllers (PLC) connected by serial networks. A central VME based PLC resides in a Control System Rack and communicates with the Front-End Computers over the VME backplane. This PLC then communicates with other PLCs on the local area network. The main power supplies use Allen-Bradley PLCs and the AB Data Highway Plus network. The VME PLC can globally turn on all the power supplies on its network, and can reduce the status information before passing it on to the control system. This system worked well during the sextant test.

5 ATR POWER SUPPLIES

The performance of the ATR PS's has been excellent. Both stability and reproducibility readings with an accurate DVM have shown better than the required or anticipated results, for both the short and long term. Comparisons between accurate references, shunts and DCCT's have been very good. The ultimate test has been the beam. During both runs the beam positions and beam sizes have been measured and have shown the system to have met the specifications very well.

6 CONCLUSIONS

The various components that make up the RHIC power supply system worked well together. The minor problems associated with the systems' interaction will be remedied with little difficulty.

REFERENCES

[1] Work performed under Contract No. DE-AC02-76CH00016 with the U.S. Department of Energy.