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Overview of the ATR Power Supplies [1]

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Abstract

The AGS to RHIC transfer Line (ATR) transports a variety of beams from the Alternating Gradient Synchrotron (AGS) which gets its input from the Booster Synchrotron. In turn, the Booster receives input beams from either a Tandem Van de Graaff (heavy ions) or a Linac (protons). The AGS extracts beam bunches, up to a rate of 30 Hertz, to the ATR which feeds the Relativistic Heavy Ion Collider (RHIC) starting with the sextant test in January of 1997. The ATR is made up of the upgraded U line and the new W, X and Y lines. A test in 1995 transported beam to the end of the W line. During normal operation, a pulsed switching magnet at the end of the W line will bend the beam into the X line or the Y line so that the two storage rings in RHIC are filled with counter rotating beams. The ATR line is comprised of 80 power supplies (PS's), 17 of which are upgraded AGS PS's. The remaining 63 PS's were newly purchased. These PS's range from bipolar 600 watt linear type trim magnet PS's to 1 Megawatt, thyristor, dipole PS's. Results of the commissioning runs will be presented, as well as descriptions of regulation, filtering, and analog and digital controls.

1 INTRODUCTION

Figure 1 is a layout of the AGS, ATR Line and RHIC. The upgraded U-line starts out with 7 magnets in the AGS ring. These magnets consist of 3 quadrupoles, 2 trim dipoles, and 2 gradient type dipoles. The 2 gradient dipoles are connected in series and make up the 4.25° degree bend. The ATR line has a total of 5 big horizontal bends (4.25°, 8°, 20°, 90°, 90°). The remaining magnets in the upgraded U-line in the ATR tunnel are 10 quadrupoles, 7 trim dipoles, and 4 gradient type dipoles connected in series which make up the 8° bend. The U-line then leads into the W-line which is made up of 6 quadrupoles, 6 trim dipoles, 2 pitching dipoles, and 8 gradient type dipole magnets which make up the 20° bend. The W-line then feeds both the X and Y lines. The X and Y lines are mirror images of each other. Each one contains 6 quadrupoles, 6 trim dipoles, one vertical pitching magnet and 32 gradient type dipoles. The 32 dipoles make up the 90° bend. The repeatability of all the PS's is generally ±0.01% for the large dipoles and quadrupoles and ±0.1% for the trim dipoles.

This specification applies to short and long term regulation and ripple. Five PS houses (see figure 1) are utilized for the ATR line PS's with all of the controls feeding back to the AGS main control room.

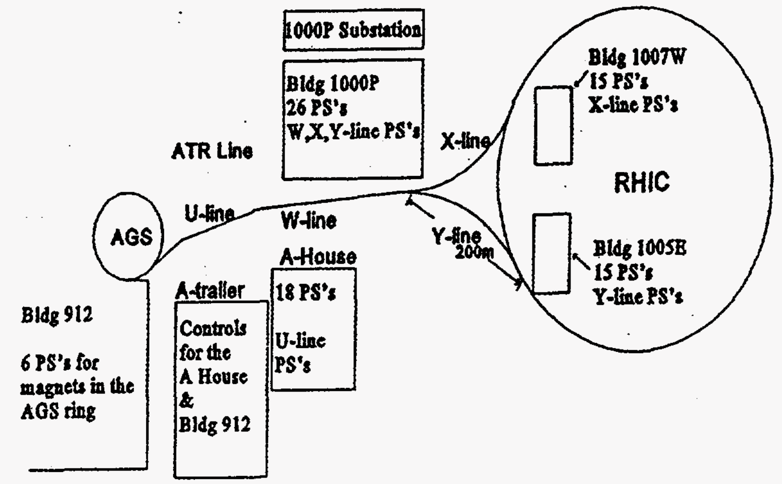

Figure:1 AGS-ATR Line-RHIC Layout

2 PS DESCRIPTION

Table I categorizes the PS's into 3 major groups, New Purchases, Upgraded and Constructed In-House.

2.1 Upgraded PS's (14)

The following are modifications for the Quad and Dipole PS's (7). A dc current transformer (DCCT) replaced a shunt for improved regulation. The regulator card was modified to accept the DCCT input and new reference. The PS controls were upgraded. The PS's were modified for OFF/STANDBY/ON operation and they were interfaced to an ALLEN BRADLEY (AB) programmable logic controller (PLC) 5/12. This PLC contains a redundant main interlock string to protect the PS.

The Trim Dipole PS's (7) had the same control modifications made as above, however, these did retain their shunt, and mechanical reversing switches were purchased and installed so they could be used as bipolar PS's for vertical or horizontal trim magnets.

2.2 Constructed In-House PS's (3)

For the SCR Dipole PS's (2), the old transformers (2400V/300V) were replaced with new outdoor oil filled transformers (13.8kV/300V) which were purchased. Refurbished contactors (outdoor, 13.8kV) from the old AGS RF system are now the switches for the primary AC power. The SCR bridges were not altered since they were

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installed new in 1985. New ripple filters were designed, installed and tested. A more sensitive ground fault circuit was designed to protect the large string of 32 dipole magnets. In order to improve the regulation, a DCCT was installed and a feedback loop analysis was performed on these PS's. They were also interfaced to a PLC.

NEW PURCHASES	UPGRADED	CONSTRUCTED IN-HOUSE
SCR-quads	SCR-quads	SCR-dipoles
50V/500A(17)	125V/400A(2)	350V/3200A(2)
50V/300A(14)	90V/2400A(2)	
LINEAR-trim-dipoles	SCR-trim-dipoles	SCR-reversible-dipole (SWM PS)
±30V/±20A(28)	±40V/±400A(7)	±125V/±3000A(1)
±20V/±100A(4)		
	SCR-dipoles	
	50V/3000A(1)	
	130V/3000A(1)	
	125V/3600A(1)	

Table I. Power Supply Groups

A special, pulsed switching magnet (SWM) PS is required to inject beam into each arc. Since this PS has to reverse polarity in a variety of timing modes to enable flexibility in the RHIC injection process, it was decided to construct it in house from an existing unit. It turned out the enclosure and a filter choke are the only remaining original parts. The new items designed, procured or fabricated and installed in house were a new contactor, ac fusing, step-down rectifier transformer, full wave secondary SCR bridge, a DCCT, a passive damped LCRC filter and a solid-state SCR reversing switch. The reversing switch needed newly-designed trigger and protection circuits. The PS received standard (RHIC) digital and analog controls based on the Waveform Generator (WFG) and interfaced via a PLC.

A network of PLC's was set up to monitor and send commands to all of the power supplies in the entire ATR line. AB PLC's were used. The 5/12 PLC was used to control up to 4 p.s.'s. The 5/12's then communicated with a higher level PLC 5/40 which acts as a master to the 5/12 slaves. This communication is via the AB Remote Input/Output Network (R I/O). The 5/40 is a VME type PLC which acts as an interface between the VME and the 5/12 field devices. There are a total of 4-5/40's, and 25-5/12's in the ATR line. All of the PLC's are connected on the AB Data Highway Plus (DH+) network. The VME crates include the AGS/RHIC Sun networked front end computers that control the beam line via the high-level application code (pet pages). The DH+ network ties all the PLC's together and allows a computer, running the AB software to monitor and/or program the PLC's from any network location.

For the analog setpoint control and monitoring, several boards were developed, that have as their basis the implementation of embedded D/A and A/D converters within the PS's. The communication between a WFG and the embedded controller is via 2 fiber optic connections. A PLD chip(s) is used to receive and convert the serial transmissions. Monitored readbacks include the D/A reference, the PS output voltage and current, the regulator error, the magnetic field (where available), and A/D $^{1}/_{4}$ and $^{3}/_{4}$ reference points. These are multiplexed and fed back to a fiber in 2 groups of 4 readbacks each. The differences between the trim PS's and the other higher precision units are that the trims do not have the above analog readbacks, (they are monitored through the MADC (see below)), and their precision is ± 11 bits as opposed to ±15 bits.

The MADC (multiplexed A/D converter system) [2] is a large digital waveform monitoring system for the RHIC accelerators. It is intended for machine fault analysis (e.g. after quenching). All the ATR PS's have isolated, buffered, analog channels that feed the local MADC via copper cables. The accuracy of this system is typically ±10 bits. The digitization rate is typically 720Hz.

A network analyzer was used to determine the closed loop bandwidth of the voltage loop and the current loop of the Constructed In-House SCR Dipole PS. A model was built in a circuit analysis program (Microcap IV) (TM) to confirm the measured results. This model will also help to predict different closed loop bandwidths based on different compensation settings for different loads without exhausting PS testing.

The voltage loop closed loop 3dB bandwidth (BW) was measured as 10Hz at a gain of -1.233dB. The simulation of the voltage loop has a 3dB BW of 12Hz and a gain of -1.494dB. Figure 2 is a photo of the measured Frequency and Phase Response of the current loop. The photo shows a closed loop 3dB (BW) of 4Hz and a gain of +0.03195dB. Figure 3 is the result of the circuit simulation which shows a 3dB BW of 3.525Hz and a gain of -0.027dB.

All three of the Constructed In-House PS's had new passive damped, filters designed and installed. The 350V/3200A PS's require a regulation of ±0.01% of maximum. The ripple filters were designed for ±0.002% maximum peak-to-peak current ripple near the final operating point. At the operating current of 3200A the 360Hz voltage ripple was measured before the filter. This voltage ripple before the filter was 160V peak to peak and the 360Hz voltage ripple after the filter was 6V peak to peak. This is an attenuation of approximately -28.5dB at 360Hz and along with the time constant of the magnets this well exceeds the specification.

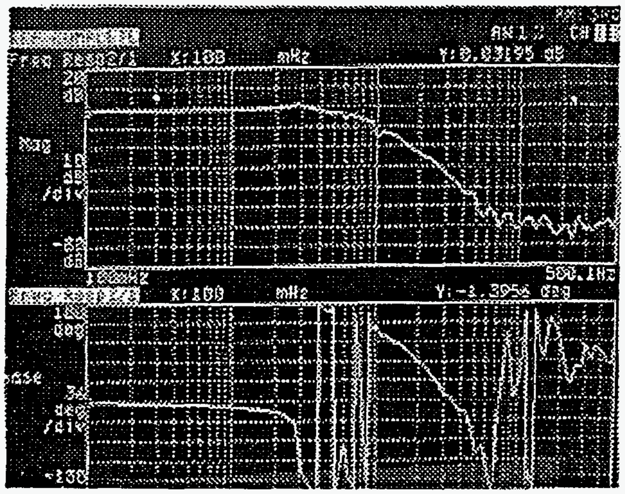

Figure: 2 Current Loop Measured Frequency and Phase Response

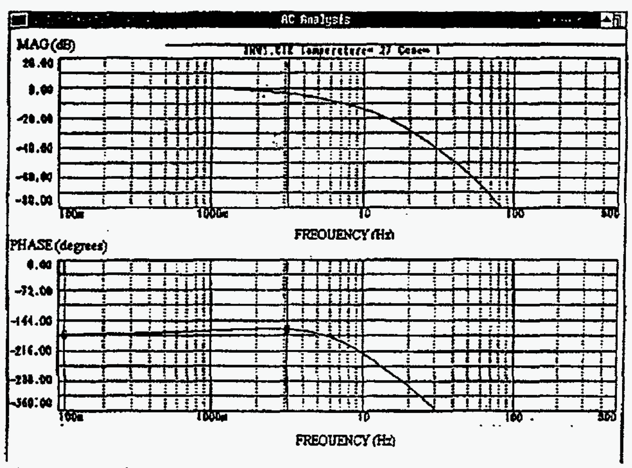

Figure: 3 Current Loop Frequency and Phase Response Simulation

3 PS COMMISSIONING RESULTS

During the ATR run in 1995 some problems were encountered. The PS for the 4.25° bend tripped off on a ground fault. After making an access into the AGS ring it was determined that a metallic water hose was touching the magnet core. The filter damping resistor in the new SCR quad PS's needed to be replaced because the power rating was too low. One of the AC breakers in the new SCR quad PS's overheated and was replaced because the AC connections were loose.

During the ATR run of January 1997 the switching magnet PS had a bad temperature sensor on the filter choke which was replaced. In one instance during a security system tripout both of the large Dipole PS's tripped off and the substation breakers tripped off as well. The cause of this still needs to be determined. We suspect an AC line transient. Two of the Linear PS's had some of their MOSFETS short out when all the PS's in the ATR line were sent to their maximum current due to a network problem that occurred. The MOSFETS were replaced after spare PS's were installed.

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 [3],[4] and have shown the system to have met the specifications very well.

4 CONCLUSION

The two commissioning runs of 1995 and 1997 have proven very successful. The beam has been transported down to the end of the of the W line in 1995 and through one sextant of RHIC in 1997. Much has been learned about the operation of the PS's. The last test of the ATR line will be in 1999 when the X-ARC PS and the switching magnet PS will be completely tested. The switching magnet PS was used as a DC PS for the 1997 run. In 1999 the PS will be required to reverse the current through the magnet so as to bend the beam down the Y-ARC and then down the X-ARC.

5 ACKNOWLEDGMENTS

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