RHIC INSERTION REGION SHUNT POWER SUPPLY SIMULATION *

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Abstract

A new heavy ion collider called the Relativistic Heavy Ion Collider (RHIC) is now under construction at Brookhaven National Laboratory (BNL) and is scheduled to be completed in June 1999. The collider requires superconducting magnets. Power supplies are required to supply currents to these highly inductive superconducting electromagnet loads. The RHIC Insertion Region contains many shunt power supplies to trim current of different magnet elements in a large superconducting magnet circuit. Shunt power supplies were chosen over all trim magnets or individual power supplies to reduce construction costs. The power supplies in the Insertion Region must be tunable. An understanding of the interaction between these power supplies was critical in determining what type of technology should be chosen in procuring these power supplies. The circuit analysis program MicroCap V by Spectrum Software (TM) was used to simulate the entire RHIC collider ring Insertion Region power supply network. Results of the absolute and dynamic error of the magnet currents are presented over the entire ramping cycle from acceleration to storage. A description of the power supplies regulation loop models is also discussed.

1 INTRODUCTION

The Relativistic Heavy Ion Collider is made up of six sextants. The simulations performed started with a single shunt p.s. model. A single sextant was modeled next. This single sextant was simulated with 4 different variations. These variations included changing the gain and bandwidth of the current loops and also observing the effect of current varying magnet inductances. Finally a simulation of the complete ring was performed. The interaction between the p.s.'s was analyzed by observing the magnet current error during the ramping of the p.s.'s. Each power supply was modeled after a typical 12 pulse SCR p.s. The current loop and voltage loop bandwidths that were used in the model were typical of a 12 pulse SCR p.s. The current loop gain and 3dB bandwidth were adjusted to observe the effect on the magnet current error.

2 SINGLE SHUNT PS MODEL

Figure 1 is a block diagram of the single shunt p.s. model. The nested power supply is p.s. Q7 and the outer p.s. is Main p.s. (p.s. QF). Both p.s.'s had an inner voltage loop with a 100Hz bandwidth. Both p.s.'s had an outer current loop. The bandwidth of the current loop for the Main p.s. was 3.5Hz and the DC gain was 104dB. The bandwidth of the current loop for the Q7 p.s. was 5 Hz and the gain was 86dB. The magnet inductances are typical of the magnet inductances for the complete ring.

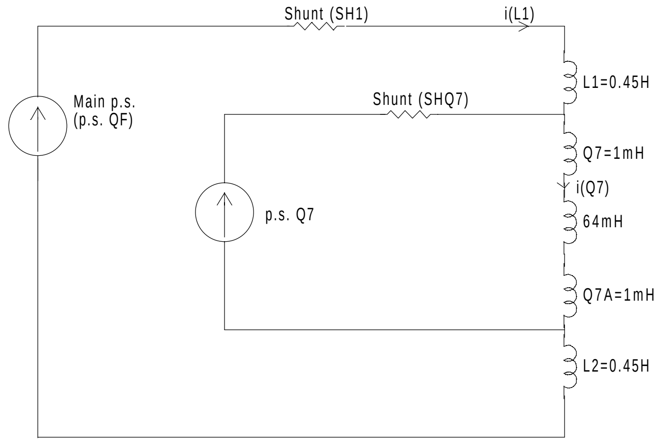

Figure: 1 Single Shunt P.S. Model

Figure 2 is a diagram of the different regions in the current waveform as the current ramps up. The waveform is broken up into nine regions. These nine regions are define as follows:

1. Injection
2. Start Acceleration
3. Acceleration
4. Finish Acceleration
5. Acceleration Done
6. Start Beta Squeeze
7. Ramp Squeeze
8. Finish Beta Squeeze
9. Storage

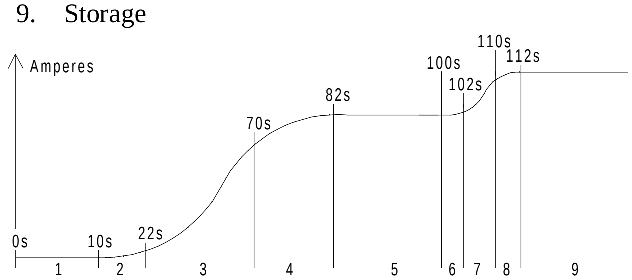

Figure: 2 Current Waveform

The simulation performed on the single shunt p.s. model revealed that the Q7 dynamic magnet current error was greatest in the Region 2. The Q7 maximum dynamic magnet current error in this region was 0.045% of the Q7 magnet current.

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3 SINGLE SEXTANT PS MODEL

The next step in the simulation was to go from a single shunt p.s. model to a single sextant [2] model as shown in the block diagram of Figure 3.

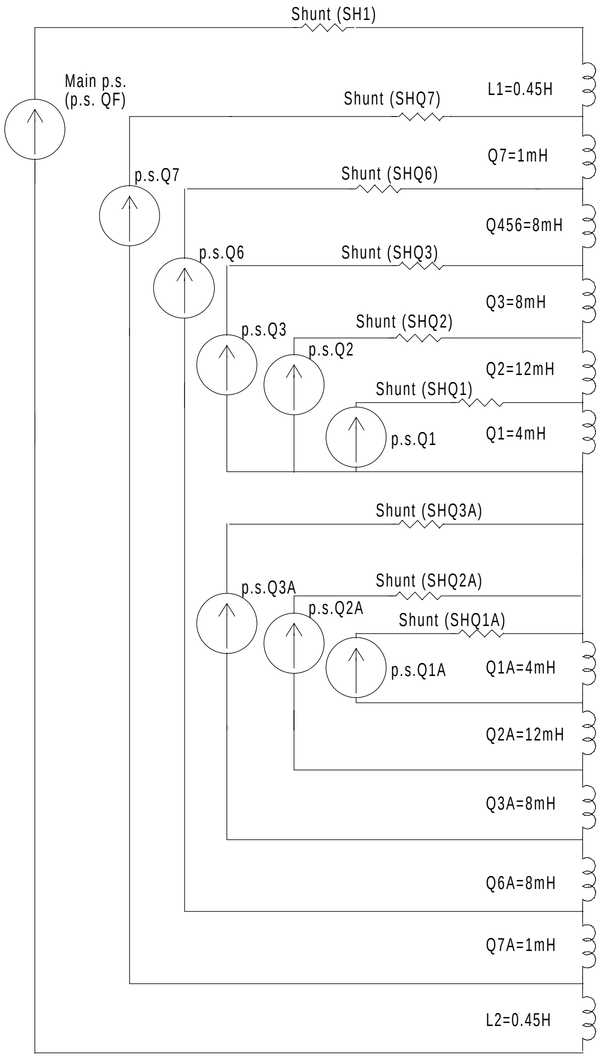

Figure: 3 Single Sextant PS Model

This single sextant model consists of 12 magnets and 9 current regulated p.s.'s. Four Simulations were run on the single sextant model. Once again the magnet inductances are typical of the real magnet inductances. Each one of these p.s.'s were ramped with the true current waveform that was required in the magnets. Table 1 and Table 2 contain data regarding the characteristics of the p.s. regulation loops for this single sextant simulation 1. Table 3 contains data regarding the magnet currents [1] and Table 4 contains magnet current errors (first 3 regions) for this single sextant simulation 1. In simulation 1 all of the p.s.'s (except psMain) have a DC gain of 86dB. PsMain has a DC gain of 104dB. The 3dB bandwidth of all of the p.s.'s was between 2 Hz and 23Hz for Simulation 1. The magnet inductances did not vary with current in this simulation. This simulation also showed that the maximum dynamic magnet current error

Circuits	3dB BW (Hz)	Open Loop DC Gain (dB)	Open Loop 1Hz Gain (dB)
psMain	3.45	104	9.63
psQ7	1.98	86	9.64
psQ456	4.0	86	21.34
psQ3	4.25	86	22.02
psQ2	14.91	86	25.08
psQ1	23.01	86	31
psQ3A	4.25	86	22.02
psQ2A	14.91	86	25.2
psQ1A	23.01	86	31

Table 1. Simulation 1 Regulation Loop Characteristics

Circuits	Open Loop 0dB Crossing (Hz)	Open Loop Phase Margin (degrees)
psMain	3.01	83.57
psQ7	1.94	87.02
psQ456	9.33	110.13
psQ3	4.77	101.61
psQ2	12.83	85.78
psQ1	14.21	69.91
psQ3A	4.77	101.61
psQ2A	12.83	85.73
psQ1A	14.21	69.91

Table 2. Simulation 1 Regulation Loop Characteristics

Circuits	Region 1 (A)	Region 5 (A)	Region 9 (A)
psMain	560	4500	4590
psQ7	68.42	550	110
psQ456	0	0	450
psQ3	-28	-225	-183
psQ2	3	25	-34
psQ1	5.23	42	150
psQ3A	-28	-225	-183
psQ2A	3	25	-34
psQ1A	5.23	42	150

Table 3. Simulation 1 Magnet Currents

Magnets	Absolute Max % Region 1	Dynamic Max % Region 2	Dynamic Max % Region 3
QF	7E-6	0.03	0.025
Q7	7E-6	0.045	0.037
Q456	7E-6	0.047	0.038
Q3	0.174E-3	0.05	0.04
Q2	0.155E-3	0.051	0.042
Q1	0.123E-3	0.051	0.042
Q3A	0.174E-3	0.05	0.04
Q2A	0.155E-3	0.051	0.042
Q1A	0.123E-3	0.051	0.042

Table 4. Simulation 1 Magnet Current Errors

occurred in Region 2. This agrees with the single shunt p.s. simulation. The maximum dynamic magnet current error, in Region 2, varied from 0.03% of magnet current to 0.051% of magnet current.

The single sextant simulation was run a second time, in simulation 2, but this time with current varying magnet inductances to study its effects. The inductances varied by as much as 10% of their nominal value, as a function of current. In this case, the maximum dynamic magnet current error, in Region 2, also varied from 0.03% of magnet current to 0.051% of magnet current.

The single sextant simulation was run a third time, in simulation 3, with the DC gain dropped to 74dB on all p.s.'s except psMain. The gain was dropped to see how much the magnet current error would increase. The maximum dynamic magnet current error, in Region 2, varied from 0.03% of magnet current to 0.14% of magnet current. Here the 12 db decrease in gain caused the dynamic magnet current error to increase by almost 3 times.

The single sextant simulation was run a fourth time, in simulation 4, once again with the 74dB gain and with current varying inductances The current varying inductances do not have much of an effect. The maximum dynamic magnet current error, in Region 2, varied from 0.03% of magnet current to 0.14% of magnet current.

4 COMPLETE RING PS MODEL

The complete ring [2] ps model was made up of six of the single sextant models. The simulation was run on a 150MHZ pentium computer with 32 Mb of RAM. To calculate the magnet current errors of one sextant took approximately 15 hours of run time.

In this simulation all of the p.s.'s (except psMain) have a DC gain of 74dB. PsMain has a DC gain of 104dB. The 3dB bandwidth of all of the p.s.'s was between 0.8 Hz and 25 Hz. The magnet inductances did vary with current in this simulation. This simulation showed that the maximum magnet current error occurred in the Region 2 again. This agrees with the single sextant p.s. simulation. The maximum dynamic magnet current error, in Region 2, varied from 0.04% of magnet current to 0.15% of magnet current. Table 5 and Table 6 contain data regarding the characteristics of the p.s. regulation loops for this complete ring simulation. Table 7 contains magnet current errors (first 3 regions) for this complete ring simulation.

5 CONCLUSIONS

These simulations show that the maximum magnet current error occurs in Region 2, the Start Acceleration region. In the complete ring model the maximum error was found to be near 0.15%. The maximum allowable error is 0.3% of magnet current. Since the magnet current errors from the simulations are less than 0.3%, the p.s.'s which are used in the ring shall have regulation loop characteristics which are close to those in this simulation. PsQ7 shall be a 20V (600A) 12 pulse SCR p.s. PsQ456 shall be a 15V (450A) 12 pulse SCR p.s. PsQ3 shall be a 15V (300A) 12 pulse SCR p.s. PsQ1 shall be a 15V (200A) 12 pulse SCR p.s. PsQ2 shall be a bipolar switchmode ±15V (±150A) p.s.

Circuits	3dB BW (Hz)	Open Loop DC Gain (dB)	Open Loop 1Hz Gain (dB)
psMain	3.57	104	10.76
psQ7	0.8	74	-7.86
psQ456	25.6	74	11.65
psQ3	2.33	74	11.21
psQ2	5.21	74	13.6
psQ1	1.94	74	6.23
psQ3A	2.31	74	10.24
psQ2A	5.2	74	12.85
psQ1A	1.92	74	6.25

Table 5. Complete Ring Regulation Loop Characteristics

Circuits	Open Loop 0dB Crossing (Hz)	Open Loop Phase Margin (degrees)
psMain	3.03	79.76
psQ7	0.69	62.85
psQ456	18.45	70.67
psQ3	3.63	90.49
psQ2	4.1	73.81
psQ1	2.66	99.84
psQ3A	3.62	90.29
psQ2A	4.06	73.81
psQ1A	2.68	99.74

Table 6. Complete Ring Regulation Loop Characteristics

Magnets	Absolute Max % Region 1	Dynamic Max % Region 2	Dynamic Max % Region 3
QF	7E-6	0.041	0.036
Q7H	1.64E-3	0.111	0.094
Q456H	1.64E-3	0.12	0.102
Q3H	0.85E-3	0.13	0.11
Q2H	0.94E-3	0.136	0.114
Q1H	1.1E-3	0.152	0.125
Q3J	0.85E-3	0.13	0.11
Q2J	0.94E-3	0.136	0.114
Q1J	1.1E-3	0.152	0.125

Table 7. Complete Ring Magnet Current Errors

6 REFERENCES

[1] S. Tepikian et al., "Tuning Curves", April 1994, RHIC Application Note, Number 23.

[2] The RHIC Design Manual