



RHIC Power Supplies, Quench Protection & Detection Systems, Early System Challenges

George Ganetis & Donald Bruno

July 10th

 @BrookhavenLab



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Introductions

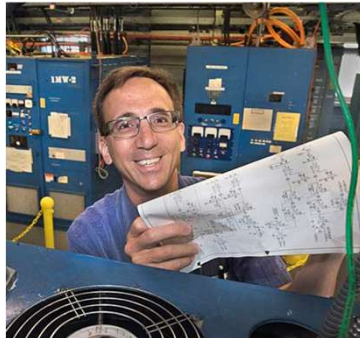
George Ganetis

Technical Lead for
Superconducting
Magnet Electrical
Systems 1995 to 2005



Don Bruno

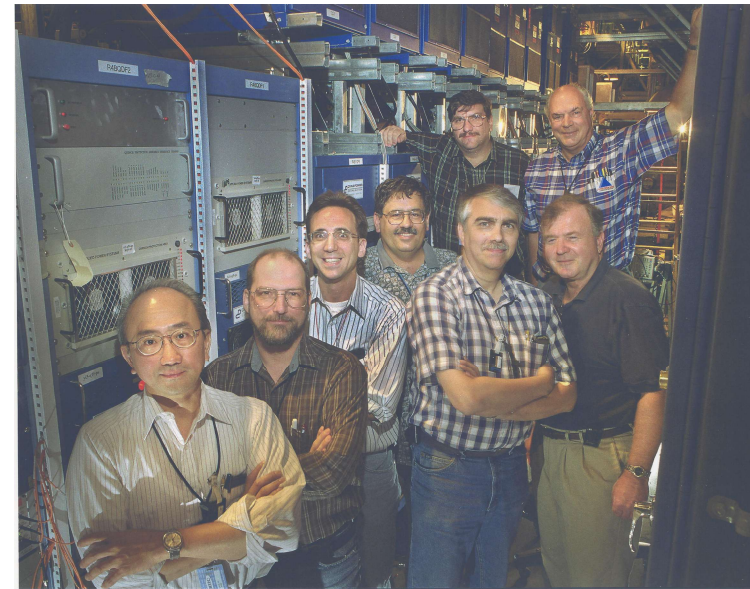
Technical Lead for
Superconducting
Magnet Electrical
Systems 2005 to 2025



Notice to Audience – There will be a large amount of information in the slides. We will not be reading the text and will only touch on the most important parts. Read the full text if you want to understand the scope of the work that was accomplished.



Engineering Staff 1999



Wing Louie
Carl Schultheiss
Donald Bruno
Bob Lambiase
Paul Ribaud
Tom Wild
George Ganetis
George Sintchak

Plus, many support engineers, technicians and designers that greatly contributed to RHIC Superconducting Magnet Electrical Systems

RHIC Power Supplies, Quench Protection & Detection Systems, Early System Challenges - Topics

- First Sextant Test - 1997
- RHIC Commissioning- 1999 Full Ring
- RHIC Run 1 - 2000
- RHIC Run 2 – 2001
- RHIC Run 3 – 2002
- RHIC Run 4 – 2003 – 2004
- Summary

First Sextant Test - 1997

Beam Tests

The Sextant test was a complete system test for RHIC overall systems. It had sectors 5 & 4 superconducting magnets, cryogenic systems, vacuum system, power supplies, quench protection systems, controls and the injection system integrated so a gold ion beam could be sent through to a fixed target. The beam tests were limited to injection energy. This was a huge success for the RHIC project.

Testing Without Beam

After the tests with beam were completed, the sextant was kept cold for 3 additional weeks to allow system tests without beam.

- The power supplies controls went through an extensive series of tests that included aspects of the high level software, such as the ramping manager and the sequencer.
- The Main Magnet power supplies Ramp & Flat-top modules were used to ramp the series connect Dipole and Quadrupole magnets to 5500 Amps. This also proved the superconducting bus designs with the many soldered joints. The 5500 amps was held for 12 hours and over 200 ramps were done.
- The quench protection/detection systems were used for all the testing with beam and no beam.
- The quench detector systems was tuned for ramps at 80 A/sec and it detected a spot heater quench on a fast ramps at a level of 25 mV. This proved the quench detector could determine a quench in a large voltage signal during a ramp. Four other magnet quenches were done with warmup heaters.

First Sextant Test - 1997

Testing Without Beam

- Interaction region quadrupole shunts and correction systems that were not used during beam testing were tested (such as sextupoles and gamma-T quadrupoles). All superconducting shunt buses in interaction regions 4 and 5 and the trim quadrupole circuits were powered to their maximum currents.
- Problem areas identified included the poor performance of SCR switches, excessive noise on the current RTDL signal, and instability of the current set-point interface on the current regulator.

RHIC Commissioning- 1999

Summary of Power Supply Test Run

- Operation of all installed p.s. in both blue and yellow ring to a dipole arc current of approx. 2000 Amps. This included all insertion p.s. operating in their nested loops.
- Yellow ring achieved a ramp rate of 6.3 Amps/sec. with only the flat-top p.s. operating. This included all insertion p.s. operating in their nested loops.
- Blue ring achieved a ramp rate of 10.0 Amps/sec. with both ramp and flat-top p.s. operating. This included all insertion p.s. operating in their nested loops. This was done on the last day of testing.
- Found problem with an interaction between the dipole ramp power module and its occ (output circuit compartment). A high voltage transient would develop across the SCRs of the ramp power module when the quench protection switch was opened at low currents. This transient was greater than the reverse voltage rating of the ramp power module's SCRs. This caused six SCRs to fail in the yellow ramp power module.
- Explored methods to reduce booster interaction in the insertion p.s.
- Powered two Quad Trim magnets with bi-polar 150 A p.s. to a level of 90 Amps. This was a complete system test that included controls, quench protection assemblies, and balancing of the quench detector.
- The testing of the DX quench heater p.s. **DID NOT** take place because of a problem that developed in the cryogenic system that caused p.s. testing to stop 10 hours ahead of schedule.

RHIC Commissioning- 1999

Power Supply Controls Problems

- WFG glitch - WFG will go to new value by its self then return to the correct value. Before the proper implementation of the max. excursion factor the Iref would do this in one 720 Hz clock. Now it can take many sec. for this to take place.
- RTDL glitch - This seems fixed on a global level, but I have seen it at one service bldg.. This could be a hardware problem.
- MADC noise – Some location need improvements. The sextupole signals were very noisy.
- PLC controls – There are still intermittent problems where commands sent to a p.s. do not seem to get there. Also when reading the status of a p.s. there are times when they are not correct.
- P.s. status reading rate – This rate can be as high as 20 sec. on a pet page. Use of scripts and how the commands are ordered can minimize the apparent time it takes to read the status.
- WFG initialization – If a FEC had to be re-booted it requires an operator to re-initialize the WFG. Also one has to be able to confirm that this initialization was preformed.

RHIC Commissioning- 1999

Ramping Software

- Initialization – It required too much operator intervention to make sure all WFG were properly initialized. A less skilled operator some times missed required steps.
- Data base configuration – It seemed very complex to load different ramps. During p.s. test run loading different levels was most cumbersome. (question – who is fred12 and why is he located at gorilla)
- Ramp Testing – It was difficult to confirm if the output of the WFGs were correct. A more efficient way to confirm all WFG are putting out the correct waveform is required. This must be done before any power supply is controlled by it. Wire up information has to be included in the WFG readbacks.
- Operator controls – Many times a wrong button was clicked on the manger that caused the ramp to crash the p.s. system.
- Diagnostic features – Need capability for ramping a signal p.s. one at a time.

RHIC Commissioning- 1999

Power Supply, Quench Protection, and Quench Detection Problems

Uni-polar Insertion P.S.

- DCCT data valid signal is not interlocked.
- P.S. powering low inductances have significant booster interaction.
- Off switches on front panel board are failing causing p.s. to go to the off state.
- Defective relay on the current regulator card causes the Iref. signal to fail.

Main P.S.

- Interaction between quench protection switch and ramp power module caused high voltage transient to short SCRs in ramp power module.
- DSP code still needs some work to improve transitions between ramp and flat-top power modules.
- Booster interaction needs to be minimized.

50 A P.S.

- Off switches on front panel board are failing causing p.s. to go to the off state.
- PLC causes p.s. to go to off state when FEC gets re-booted.
- Early version of p.s. need modification to prevent noise from triggering over-voltage crowbar.

Sextupole P.S.

- DCCT card has a temp. Sensitivity.
- DAC resolution may be too coarse.

RHIC Commissioning- 1999

Power Supply, Quench Protection, and Quench Detection Problems

Quench Protection Assemblies

- Fan interlock switches fail open.
- IGBT driver board sometimes gives false over-current faults.
- IGBT driver board has high pot problem.
- Micro-controller needs software change to fix error found in state diagram.
- Models RQP-10 and RQP-9 have too high a current going through its crowbar SCRs.

Quench Detection

- Temp. compensation system not working well for large temp. changes. Also separate problem exists in 1010A with temp. compensation system.
- Warm-up mode has to monitor ground current of the .1 Amp. p.s. used for monitor resistances of magnet coils.
- RTDL glitches still can cause system to crash.

RHIC Commissioning- 1999

Major Tasks Not Done

- Installation and test of bi-polar p.s.
- Construction and installation of the gamma-t jump p.s.
- Test of DX quench heater p.s.
- Implement cryo-data transfers
- Operation of p.s. system at high ramp rates and at high currents

Major Challenges During The Commissioning Run

- Environmental conditions – We had record temperatures 105 while commissioning air cooled equipment using outside air!
- The systems were all new and testing could only be done at magnet operating temperatures.
- The insertion regions shunt quadrupole nested power supplies was a very complex systems that took effort to get the current loop compensations network tested and ready for operations.
- The complexity of the power supplies, quench protection, and quench detection required system experts to run the systems. We a very limited number of experts.

RHIC Commissioning- 1999

Ramping and Sequencing Software Action Items

Ramping Software

- Initialization – It required too much operator intervention to make sure all WFG were properly initialized. A less skilled operator some times missed required steps. The ramp or magnet managers will have to monitor this and or alarms will have to be made that will let an operator know when some thing is not properly initialized or have the correct firmware version.
- Loading ramps – It seemed very complex to load different ramps. During p.s. test run loading different levels was most cumbersome. Ramp manager will need improvements.
- Operator controls – Many times a wrong button was clicked on the manger that caused the ramp to crash the p.s. system. The manager will have to keep track of what operation is being done and don't allow any out of sequence.
- Rounding Errors – This will have to be investigated.
- Ramp Testing – It was difficult to confirm if the output of the WFGs were correct. A more efficient way to confirm all WFG are putting out the correct waveform is required. This must be done before any power supply is controlled by it. Wire up information has to be included in the WFG readbacks.
- Diagnostic features – Need capability for ramping a single p.s. at a time. More error messages are needed to get reasons for failures in the managers and ADOs.
- Other things to do – Download sequence of ramps, live ramps, RF control and Gamma t control.

RHIC Commissioning- 1999

Ramping and Sequencing Software Action Items

Sequencing Software

- Improve GUI – Display of the time line.
- WFG manger – Smoother integration, Multiple ramps in one “ store “.
- Exception handling – Need to define what state to return to after failure.
- Integration with data acquisition – Have to be able to take orbit data at specific stepstones.

RHIC Commissioning- 1999

Power Supply Controls Problems Action Items

- WFG glitch - WFG will go to new value by its self then return to the correct value. Before the proper implementation of the max. excursion factor the Iref would do this in one 720 Hz clock. Now it can take many sec. for this to take place.
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- MADC noise – Some location need improvements. The sextupole signals were very noisy.
- PLC controls – There are still intermittent problems where commands sent to a p.s. do not seem to get there. Also when reading the status of a p.s. there are times when they are not correct.
- P.s. status reading rate – This rate can be as high as 20 sec. on a pet page. Use of scripts and how the commands are ordered can minimize the apparent time it takes to read the status.
- WFG initialization – If a FEC had to be re-booted it requires an operator to re-initialize the WFG. Also one has to be able to confirm that this initialization was preformed.

RHIC Commissioning- 1999

Power Supply Controls Action Items

- WFG glitch – Improve diagnostic tools and error messages in trouble shooting this problem. These tools should be able to be used by non-experts.
- RTDL glitch - – Improve diagnostic tools and error messages in trouble shooting this problem. These tools should be able to be used by non-experts.
- MADC noise and offsets – Some location need improvements. The sextupole signals were very noisy and need the buffer chassis installed.
- PLC controls – Diagnostic tools are required to trouble shoot the intermittent problems where commands are not received by a p.s. and status information is not correct.
- P.s. status reading rate – This rate need improvement. The rate can be as high as 20 sec. on a pet page.
- Sextupole DAC Resolution – Need to improve this to 16 bits.

RHIC Commissioning- 1999

Electrical Systems Group's Task List After Commissioning Run

Main P.S.

- Install transorbs across all main p.s. SCRs on all power modules.
- Replace blown SCRs in yellow ramp power module.
- Re-connect output cables of the yellow ramp power module.
- Install front panel lockable switches for A.C. control power.
- Install meters, instrumentation, and test panel to monitor SCR voltages, AC line voltage, and line current.
- Test ramp and flat-top p.s. system using test load of 300 uH and .3 ohms. This will enable DSP software to be tested for the transition between flat-top to ramp and ramp to flat-top.
- Complete A.B. PLC software for the remote control of the main p.s. . This also includes final implementation of all the p.s. interlocks.
- Test p.s. output filter capacitors for shorts and then place all p.s. in a short circuit at each valve box.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures

50 A Corrector P.S.

Finish installation of 50 A p.s. for high order corrector families.

- Repair 50 A p.s. that failed during the summer run.
- Put jumpers in at CQS trees so p.s. can operate while the corrector coils are at room temp..
- Install jumpers in low res. DAC cards that connect Iref. signal low to ground.
- Check what the fc of the output filter of the low res. DAC card is. It should be about 20 Hz..
- On all 50 A correctors that are repaired, the off switch should be replaced. On units in the tunnel it is recommended that the off switches on these be replaced on an as needed basis only. A cleaning method is being investigated to see if it will work. If it does all off switches will be cleaned.
- The modicon PLC software has to be changed so when re-booting a FEC it will not turn off a 50 A p.s..
- The up-date rate of reading the status (On, Off, Standby, and Faults) of the 50 A corrector p.s. has to be re-explored. This needs to be faster.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.
- Investigate high noise at some MADC location

RHIC Commissioning- 1999

Electrical Systems Group's Task List After Commissioning Run

Sextupole P.S.

- Find temp. sensitive components on D.C.C.T. card and find a less sensitive component or different solution.
- Investigate turn on transient on the buffer amplifiers for the p.s..
- Determine with Acc. Physics on the DAC resolution requirements. If 16 bits is required then 24 new cards have to be designed and built.
- Investigate MADC read-back noise on the sextupole p.s. buffered signals. The noise level was about 1 Amp. , this is compared to a setpoint of .8 and 1.8 amps.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

Uni-polar Insertion P.S. (Dynapower)

- Modify control chassis back-plane so the DCCT data valid interlock is included in the error fault interlock.
- Modify SCR firing control board to improve frequency response, This is needed to minimize the booster interaction (A.C. line disturbances).
- Modify voltage loop time constants on the voltage regulator card to increase bandwidth and gain to minimize booster interaction.
- Modify voltage regulator card so the maximum voltage output is the rated voltage. Install voltage clamp.
- Clean and Test all off switches on the control card. Replace any switch that does not pass test.
- Test all Electro-dyne relays on current regulator board (two on each card). Replace any that fail test.
- Test all output filter circuits for shorted capacitors. Then put p.s. on short circuit for test.
- Investigate higher noise on the 4/20 ma signals on the buffer cards for the 2000 Amp. p.s. in service bldg. 1004B.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

RHIC Commissioning- 1999

Electrical Systems Group's Task List After Commissioning Run

Bi-polar P.S. (Suncraft)

- Test the 2 150 amp. units on short circuit and indentify any problems. A high frequency oscillation was observed on the power amp. when testing on a superconducting load.
- As power supplies get delivered from vender, install and test units in service bldg. , These test will be done on a short circuit load.
- Make sure modifications done on the un-polar p.s. are done to these p.s.(off switch on control card and test o relays on current regulator card.
- Label quad trim p.s. cables with magnet coil site wide names and lug cables.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

Gamma-T Jump P.S.

- Finish designs and start construction of proto-type p.s.
- Start production of p.s. in AGS factory.
- Install p.s. in alcove when done.

Quench Protection

Main P.S. Circuits

- Order 9 (8 + 1 spare) high voltage p.s. for charging pfn circuits in the OCC. (Output CircuitsCompartment)
- Order 14 (12 +2 spares) high forward voltage drop diode stacks. These diode will clamp the high voltage transient that the pfn circuits produce during low current shut offs
- Get all O.C.C interlocks operational and tested.
- Change A.C. power for quench protection system in the O.C.C. to go through the front panel switch of it's main p.s.. (This will allow for a simpler lockout of the main p.s. system.)
- Change A.C. power for 6000 Amp. quench protection switches in bldg. 1010A. The power to the UPS has to remain on even when the main disconnect switch for the bldg. is turned off.
- Start re-write of small modicon PLC (located in the 4 6000 Amps SCR switches) software. This to to clean up messy latter logic code.
- Test ground current monitoring circuits and make sure they read correctly on " pmveiw " program.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

RHIC Commissioning- 1999

Electrical Systems Group's Task List After Commissioning Run

Insertion P.S. Circuits

- All fan interlock switches have to be replaced with low current version.
- Modify IGBT boards to prevent false over-current faults.
- Change crowbar resistor on RQP-10 and RQP-9 on all units. This will lower current in crowbar SCRs to specified value.
- Modify micro-controller software to fix an error in state diagram.
- Test crowbar voltage and high-pot all QPAs (Quench Protection Assemblies)
- Install line filters on rack mount and stand alone QPAs.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

Sextupole P.S. Circuits

- All fan interlock switches have to be replaced with low current version.
- Modify IGBT boards to prevent false over-current faults.
- Modify micro-controller software to fix an error in state diagram.
- Test crowbar voltage and high-pot all QPAs (Quench Protection Assemblies)
- Build and install 6 QPAIC (Quench Protection Assembly Interface Chassis) for sextupole circuits.
- Write software needed for Modicon PLC and for pet pages for the control of these QPAICs.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

RHIC Commissioning- 1999

Electrical Systems Group's Task List After Commissioning Run

Quench Detection System

- Investigate problem with temp. compensation system on the QD (Quench Detectors) in 1010A service bldg.
- Calibrate the temp. compensation system on all QDs for large temp. changes.
- Add sine wave calibration signal to all QDs.
- Add ground current monitor to warm-up current monitor device. If there is any significant ground current then the QDs will turn off the warm-up heater power supplies.
- Implement data transfers of cryo-data. This is to include warm-up data and currents going through gas cooled leads.
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.
- Develop better de-glitchers for bad data from the RTDL. Limit maximum di/dt value.

DX Quench Heater System

- Finish installation and test of all DX quench heater p.s..
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

Magnet Warm-up Heater System

- Install .1 Amp power supplies in permanent location.
- Design and install connector system for .1 Amp p.s. that will allow easy connection to magnet circuits at 1004B service bldg.
- Add ground sense resistor for .1 Amp. p.s..
- Prepare spares list and order critical components.
- Complete schematics and operation procedures.

There were 76 tasks that was identified during the commissioning run that needed to be addressed.

RHIC Run 1 - 2000 Retreat Slides

Power Supplies And Ramping

New power supplies for next run - J. Sandberg

- 150 & 300 Amp bipolar insertion p.s.
- Gamma T Jump p.s.
- Snake magnet p.s.

Hardware reliability - C. Schultheiss

- This report compiles the data from the RHIC Power Supply Group Logbook and the experience of the RHIC Power Supply Engineers. It then reports any systematic hardware problems revealed and discusses the efforts being made to correct these problems.

Planned improvements during shutdown – G. Ganetis

- Power Supplies – Main, Insertion, Sextupole, 50 Amp Corrector
- Quench Protection – Quench Protection Assemblies, 6KA Quench Protection Switches, DX Quench Heater P.S., External quench link cable connections
- Quench Detection – Hardware and software
- Magnet Electrical
- General Items

Controls Issues – T. Clifford

- Alarms
- Reliable Data Delivery
- Momentum PLC
- MADC Improvements
- Helper Applications
- Post Mortem

RHIC Run 1 - 2000 Retreat Slides

Power Supplies And Ramping

Ramping Hardware Issues – D. Bruno

- Power supply current errors and magnet current errors will be discussed as well as the original magnet current error specifications.
- Models vs Measurements will be presented.
- Power supply current errors have been measured using the snapramps and are compared to the power supply current errors in the models.

Ramping - Software Issues – J. van Zeijts

- Tune Control using Tune Feedback
- Snapback Correction using RTDL frames
- Automated Orbit Control Feed-Forward
- Required upgrades to the on-line Model

RHIC Run 1 - 2000 Retreat Slides

Planned Improvements During Next Shutdown

Power Supplies

Main Power Supplies

- Will put all main power supply controls on UPS to decrease time it take to recover after an AC power disturbance.
- Fix DCCT glitches on blue dipole main power supply during power supply shut offs. This is to minimize false quench detector trips of the DX magnets. (These DCCT glitches will cause all 12 DX magnets to quench. It will take up to four hours to recover.)
- Find and repair intermittent main p.s. interlock that trips main p.s..

Insertion P.S. – Unipolar (Dynapower p.s.)

- Modify all DCCT cards to desensitize them to temperature changes.
- Implement current regulator error fault to trip p.s. in the event of a high error.
- Modify filter on d.c. over-current circuit to reduce noise that could trip circuit and trip the p.s..
- If given the approval, change p.s. time constants to improve dynamic tracking error of the p.s. when ramping.

RHIC Run 1 - 2000 Retreat Slides

Planned Improvements During Next Shutdown

Power Supplies

Insertion P.S. – Bipolar (SunCraft p.s.)

- Move d.c. overcurrent sensing device (LEM) to correct position (Before crowbar lead) to allow proper protection of p.s. (This has to be done to all 150 A p.s.)
- Implement current regulator error fault to trip p.s. in the event of a high error.
- If given the approval, change p.s. time constants to improve dynamic tracking error of the p.s. when ramping.
- On trim quad p.s. add soft-grounds to all p.s. outputs. This can prevent p.s. faults during transient conditions.
- Correct any known p.s. lead reversals.

Sextupole P.S.

- Correct polarity of quench protection crowbar assemblies on all yellow sextupole circuits. (This will enable the yellow sextupole magnets to go to maximum current.
- Modify p.s. and install cabling to add analog error signal to MADCs.
- Install ground current monitoring circuits on all sextupole circuits. These signals will go to the MADCs.

50 A Corrector P.S.

- One alcove will have the micro-controllers changed in all the p.s. if resources are available. A new program in the micro-controller will be tested to determine if the number of faults decrease. (This will be the same alcove that the controls group is using to debug the new Modicon PLC.

RHIC Run 1 - 2000 Retreat Slides

Planned Improvements During Shutdown

Quench Protection

Quench Protection Assemblies (QPAs)

- Install ac line filters in stand alone QPAs.
- Install snubbing resistors across fuses in all passive QPAs to prevent high voltage condition if fuse is blown.
- Check operation of all fan switches and repair any that are not functioning correctly.
- Design and build replacement IGBT driver boards that are more immune to ac power disturbances.

6 KA Quench Protection Switches

- Modify quench link interface board to a more robust circuit.
- Replace the PFN charging resistors all four of the switches.
- Repair displays on the PFN charging p.s. on B9QPSW.
- Perform interlock test on PLC code for all four switches.

DX Quench Heater P.S.

- Install cables to bring heater p.s. analog signals to MADCs.
- Adjust heater p.s. voltages on units that are not in nominal settings.

External Quench Link Cable Connections

- Test all external (Non-control system) cables that can cause an interlock and see if movement of the cable connector end (wiggle test) will cause the quench link to drop. Develop comprehensive test sheet to document that the tests were done.

RHIC Run 1 - 2000 Retreat Slides

Planned Improvements During Shutdown

Quench Detection

Hardware

- Repair backplanes of q.d. buckets. Two of the thirty buckets have a temporary repair in them.
- Design and install a fast heart beat circuit into all quench detectors that monitor a DX magnet. The existing heartbeat will cause a trip after one second. The new heartbeat has to trip after 67 milli-seconds to protect the magnet.

Software

- Finalize routines for DX quench detection to minimize the detection time of a magnet quench during normal operation. Also ensure that during energy extraction (p.s. shut off) the quench detector does not incorrectly indicate a DX quench on a high negative di/dt value.
- Modify software to make it less susceptible for an insertion p.s. glitch to cause a trip. Will use some of the same routines developed for DX for these improvements.
- Modify sextupole type device software by adding an adaptive routine that will adjust the resistance term of the device equation to compensate for variation in the lead resistance due to temperature changes.
- Modify ADOs to allow quench detector to be logged on the controls Alarm application.
- Will have new feature that will allow multiple inductance tables. This will be used when one wants to ramp **to** different current levels. A simple script command will cause all the quench detectors to switch to a new table.

RHIC Run 1 - 2000 Retreat Slides

Planned Improvements During Shutdown

Magnet Electrical

Tunnel Magnet Electrical

- Install and electrical test three more snake magnets.
- Find and repair high resistance shorts to ground.
- Install feed-through for spare voltage taps needed for quench detection in insertion region.
- Fix open voltage tap wiring for main quad circuit in blue sector 11
- If time and resources are available add insulation around CQS trees.

Valve Box Magnet Electrical

- Tighten all insertion lead terminal screws on the 150 A gas cooled leads.
- Check torque on flag hardware for the 1600 A and 6300 A gas cooled leads.

Warm-up Heaters

- Install Warm-up circuits for snake magnets.

General Items

- Clean or replace all air filters in power supplies, quench protection assemblies, , quench protection switches, racks of p.s. , etc.
- Improved ventilation in service bldgs.
- Put critical control system chassis on UPS.

RHIC Run 2 - 2001 Retreat Slides (2/ 2002)

Planned Improvements During Shutdown Quench Detection

Existing Hardware

- Connect Q.D. UPS to control system to monitor status.
- General Maintenance – Cleaning filters and tighten Q.D. chassis high current p.s. connections.
- Re-work ceramic feedthroughs in the arc region used by the Q.D. voltage taps.

New Hardware

- Install 4 new chassis for spin rotators

Software

- The time stamps in alarm messages and file descriptors will be changed from the time the file is saved to that of the time the Q.D. circuit tripped.
- Alarm messages will be sent as soon as a Q.D. trips for all circuits in a Q.D. This requires that while one circuit is dumping quench data another circuit can still output an alarm.
- Develop routines that will determine if a real quench has occurred for sextupole, trim quad, or helical magnets
- Make changes to the DX magnet quench detection algorithm that looks for a quench right at the start of the current dump. An alternative to this could be a hardware change in the DX and D0 quench protection circuit that will allow for a slower current shut off.
- Develop a new application that can load a different inductance table easily and without using the quench detection data base editor.
- Investigate new methods that can compensate for induced voltages in voltage tap circuits that go through the helical magnets.

RHIC Run 2 - 2001 Retreat Slides (2/ 2002)

Planned Improvements During Shutdown

RHIC Magnet Electrical Systems Repairs & Modifications

- Repair CQS magnet with bad quad corrector coil.
- Electrical installation of 8 spin rotator magnet assemblies.
- Correct voltage tap wiring error at Y6D9.
- Repair 6 open voltage taps.
- Replace electrical feedthroughs on all triplets.
- Modify the electrical insulation scheme used on the arc voltage taps feedthroughs that are used by the quench detectors.
- Modify the electrical insulation scheme used on the sextupole current feedthroughs.
- Install new voltage tap feedthroughs in the insertion region for more room temperature spare voltage taps.
- Tighten all electrical connection on the top of the valve boxes

RHIC Run 3 - 2002 Retreat Slides (6/ 2003)

Superconducting Magnets, Quench Protection, And Environmental Issues That Effects S.C. Magnet Systems "Ice Balls"

RHIC Magnet Electrical Systems Repairs & Modifications – SC Magnets

Y3 Q7 Voltage Tap – The ceramic feed through had significant carbon tracks on it. It caused multiple trips of the system due to excessive ground current. We were able to nurse it during the rest of the run after it was identified. Cause of the problem was probably due to excessive moisture at the feed through. A new ceramic feed through will be installed.

HRD102 Snake (yellow sector 9) – The superconductor cable is open in # 2 (B) magnet, which is HSD 205. Current can only go through the internal quench protection resistor. The open coil is in the outer coil of HSD 205. Preliminary tests show there is 246 Ω short to ground and the short is in block # 3 of the outer coil . An autopsy of the magnet will be needed to determine the cause of the failure. This snake magnet is being removed from the tunnel and will be repaired and the re-installed.

HRD101 Snake (blue sector 9) - All four magnets have some type of short to ground. Preliminary tests puts the locations of the shorts to be by the gas cooled lead ceramic insulators. All ceramic insulators are upside down . Three of them are leaking helium. The gas cooled leads are the original one that were a short length that had a high heat load. New ceramic insulators will be installed on the magnet in the tunnel.

HRD 302 Spin Rotator (blue sector 6) - HSD 409 (A) has a low resistance short to ground at the bottom of the A + lead. The lead will be disassembled and the short repaired in the tunnel.

RHIC Run 3 - 2002 Retreat Slides (6/ 2003)

Superconducting Magnets, Quench Protection, And Environmental Issues That Effects S.C. Magnet Systems "Ice Balls"

RHIC Magnet Electrical Systems Repairs & Modifications Quench Protection

DX – D0 Quench Protection- At the start of this year's d-Au run we were quenching the DX magnets when the system would trip at high currents. The problem was determined to be incorrect triggering of the quench protection switches for the D0 and DX magnet circuits. This problem would cause excessive currents in the D0 circuit that would cause the DCCT in the power supply to malfunction. This malfunction would give an incorrect current signal to the quench detectors. The quench detector uses both D0 and DX current signals in its calculation to determine a DX magnet quench. When the quench detector got an incorrect D0 current signal it would then fire the DX quench heaters and cause a real magnet quench. The problem was finally identified in late December and new hardware was installed and tested in late January.

Quench Protection Assemblies – QPAs had 37 faults, 20 of these faults occurred during startup or on maintenance days. Almost half of them were easily recoverable faults (Fan faults). About one-third were due to infant mortality of the reworked QPAs. (All QPAs were modified during last year's shutdown.) Six faults were due to lose control cables going into the QPAs. We found that the wrong connector hardware was used. New hardware will be installed this shutdown.

With the new timing resolver system and modified snapshot and post-mortem software it was much easier diagnosing problems this year.

Quench Detector Hardware – We had only three failures this year. A low-level power supply, ac line cord, and a failed voltage reference chip on a Single Gain Mux card.

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RHIC Magnet Electrical Systems Repairs & Modifications Quench Protection

Quench Detection Software- We tried to run new software that would improve the time stamps of quenches. Unfortunately, this occurred when we were also having server problems. After fixing the server problems we still found some bugs in the software. So we ran the rest of the year on an earlier version of software. The latest version of software is now waiting for final testing.

Quench Detection Tuning- We now have a clean data set (booster not running) and will get new inductance tables for the next run that will allow faster ramps from park to injection, top energy to injection, and injection to park.

Beam Loss Induced Quenches- Over 160 real magnet quenches !

Quench Link Trip Diagnostics- Need more data from the cryo system to be available remotely and for it to be logged. (lead flows and temperatures)

General Comments –

- Due to the inefficient nature of corrector magnet gas cooled leads, condensation forms on the lead components.
- Heaters are used to prevent this condensation from forming, but they sometimes fail or are overwhelmed when there is too much gas flow going through the lead.
- In areas of the tunnel where there is high humidity “ice balls” form at the base of the lead and given enough time will engulf a heated lead.
- Large leakage currents to ground develop across voltage tap ceramic insulators. These leakage currents caused numerous system trips.

RHIC Run 3 - 2002 Retreat Slides (6/ 2003)

Superconducting Magnets, Quench Protection, And Environmental Issues That Effects S.C. Magnet Systems "Ice Balls"

RHIC Magnet Electrical Systems Repairs & Modifications – Requirements

Requirements for reducing quench detector trips.

- All voltage tap ceramic insulators should be kept above the dew-point temperature. No condensation should form on them for all operating conditions.
- Prevent long-term ice buildup on gas lines and structures that could contact voltage tap boxes.
- Monitoring of temperatures on voltage tap flanges.
- Maintain nominal flow rates on leads. Prevent 50 percent increases in flow.
- Temperature data is to be alarmed and logged on the control system.

Work to Be Done This Shutdown

- Install foam insulation on the base of every CQS lead and on all gas lines.
- Replace thermostats on all leads with new ones that will maintain a higher temperature. (from 32-48 ° F to 70-86 ° F)
- Install new 1-wire temperature monitoring system for all voltage tap feed through flanges in the tunnel and on high current leads in the valve boxes. This data will be alarmed and logged by the control system.
- Adjust lead flows back to their nominal levels.
- Re-design vacuum system for vacuum jacketed high current gas cooled leads.

RHIC Run 4 – 2003 - 2004 Retreat Slides (6/ 2004)

RHIC Systems Power Supplies ,Superconducting Magnets, Quench Protection , etc.

Work Done Before and During Run 4 Power Supplies

Corrector Power Supplies

- All 620 removed and modified
- Trips to OFF state fixed
- Parking Circuit added to p.s.
- DC Over Current circuit adjusted
- Tightened all AC connections
- Tightened all DC connections at CQS magnet trees
- Increased 208 VAC substation voltages
- Found problem with Error trips on corrector p.s.'s
- Major review of corrector p.s. schematics to determine FINAL changes to corrector p.s.'s

IR power supplies

- All 150A and 300A bipolar units removed
- Replaced shorted soft start IGBT's
- Install Relay board fix for soft start
- Add MOV's to ac inputs
- Insulated screw which caused hi-pot problems

Sextupole P.S.'s

- Added buffer for current readback signal to quench detector

RHIC Run 4 – 2003 - 2004 Retreat Slides (6/ 2004)

RHIC Systems Power Supplies ,Superconducting Magnets, Quench Protection , etc. Work Done Before and During Run 4 Power Supplies

Main Power Supplies

- New DSP code
- Regulation Error Signal interlock added
- New PLC code
- Reconfigured Soft Grounds.
- Improved mounting of Quench Protection DC Contactor snubber capacitors
- Changed DCCT connector in the Yellow Dipole.

Software Modifications

- 720Hz data added to snapshot
- Last command saved added to PLC software
- Timing resolver software improved
- Changes made to WFG manger to prevent system trips due to wrong ramp rates when off the hysteresis curve.

SC Magnets

Y3 Q7 Voltage Tap –

The ceramic feed through had significant carbon tracks on it. It caused multiple trips of the system due to excessive ground current. We were able to nurse it during the rest of the run after it was identified. Cause of the problem was probably due to excessive moisture at the feed through. A new ceramic feed through was installed .

RHIC Run 4 – 2003 - 2004 Retreat Slides (6/ 2004)

RHIC Systems Power Supplies ,Superconducting Magnets, Quench Protection , etc.

Work Done Before and During Run 4 SC Magnets

SC Magnets

- **Y3 Q7 Voltage Tap –**
The ceramic feed through had significant carbon tracks on it. It caused multiple trips of the system due to excessive ground current. We were able to nurse it during the rest of the run after it was identified. Cause of the problem was probably due to excessive moisture at the feed through. A new ceramic feed through was installed .
- **HRD102 Snake (yellow sector 9) –** Superconductor is open in # 2 (B) magnet, which is HSD 205.. An autopsy of the magnet was done , but the results were not conclusive as to the cause of the failure. This snake magnet was removed from the tunnel and was repaired and the re-installed.
- **HRD101 Snake (blue sector 9) -** New ceramic insulators were installed on the magnet in the tunnel. The gas cooled leads were made longer to decrease the heat leak.
- **HRD 302 Spin Rotator (blue sector 6) -** HSD 409 (A) had a low resistance short to ground at the bottom of the A + lead. The lead was disassembled and the short repaired in the tunnel.

RHIC Run 4 – 2003 - 2004 Retreat Slides (6/ 2004)

RHIC Systems Power Supplies ,Superconducting Magnets, Quench Protection , etc.

Work Done Before and During Run 4 Quench Protection

- **Quench Detector Hardware** – In testing the failed Rhic helical magnet in bldg. 902. A problem was found in the way the magnet voltages were being monitored for a quench. Instead of total coils being monitored we now have to monitor half coils. This required the addition of new hardware. This information was not found out until very late in the run , but we were able to install all the new hardware before the proton run.
- **Quench Detection Server-** A new NT server was installed
- **Quench Detection Software-** New software was installed that improves the time stamps of quench alarms. The latest version of software was installed late in the run and seems to be working. Also, changes were made to the DSP code to decrease the detection time in helical magnet quenches.
- **Quench Detection Tuning-** New inductance tables were developed that allows faster ramps from park to injection, top energy to injection, and injection to park.

"Ice Balls" Prevention

- Installed foam insulation on the base of every CQS lead and on all gas lines.
- Replaced thermostats on all leads with new ones that will maintain a higher temperature. (from 32-48 °F to 70-86 °F)
- Installed new 1-wire temperature monitoring system for all voltage tap feed through flanges in the tunnel and on high current leads in the valve boxes. This data was logged by the control system.
- Adjusted lead flows back to their nominal levels.
- Installed 1-wire temperature monitoring on gas cooled leads on the valve boxes.
- No down time due to "ice balls" this run.

RHIC Run 4 – 2003 - 2004 Retreat Slides (6/ 2004)

RHIC Systems Power Supplies ,Superconducting Magnets, Quench Protection , etc. Work Planed for Summer 04 and During Run 5

IR and Corrector Power Supplies

- Unipolar IR p.s.'s aux contacts error fault being fixed.
- Installing MOV's in rack mounted unipolar p.s.'s
- Fixing Error Trips for corrector p.s.'s
- Modifying Slew Rate Limiter for corrector p.s.'s (From 1kHz to 5 Hz)
- Test writing to node card ports individually

Main Power Supplies

- Adding instrumentation to monitor current in the OCC Quench Protection Main SCRs.
- Adding instrumentation to monitor gating of OCC Quench SCRs.
- Maintenance on all Phoenix style connector connections.
- **Quench Detector Hardware** - Replace temporary connection to the helical magnet voltage taps with the permanent design.
- **Quench Detection Software** – Continue testing new software over summer shut down.
- **Quench Detection Tuning** – Improve inductance tables to allow even faster ramps from park to injection, top energy to injection, and injection to park. This will be done during the start-up of the machine.
- **Quench Protection Switches** – Perform maintenance on all 6 KAmper mechanical interrupter and tighten all connection

RHIC Run 4 – 2003 - 2004 Retreat Slides (6/ 2004)

RHIC Systems Power Supplies ,Superconducting Magnets, Quench Protection , etc. Work Planed for Summer 04 and During Run 5

More “ICE Ball” Prevention

- Modify heaters and thermostats that are on the triplet corrector leads.
- Modify heaters, replace thermostats, install insulation and re-position 1-wire temperature sensors for the valve box 12 by 150 amp gas cooled leads.
- Install heaters and thermostats and re-position 1-wire temperature sensors on the valve box 1600 and 6300 amp gas cooled leads .

New Software and Software Modifications

- Temperatures from the “Ice Ball “ monitor are to be put in the modified Alarm system. (Temperature has to be below or above alarm levels for a fixed length of time to cause an alarm.)
- Need more data from the cryo system to be available remotely and for it to be logged. (lead flows and temperatures)
- UPS monitoring that will have alarms and give correct direction to operations when AC power is lost on critical systems.
- Improvement to Quench Recovery in TAPE

RHIC Power Supplies, Quench Protection & Detection Systems, Early System Challenges - Summary

- **First Sextant Test - 1997** Beam test using main quad power supply in 1004 B for dipole circuit and a Shunt ps. to power quads (plus a quad trim ps.). Beam was injected through full injector chain to a beam dump in sector 4. No beam test powered dipole & quad circuits to 5500 amps and tested quench detector capability to detect a bus quench while ramping at 89 amps/sec using a spot heater.
- **RHIC Commissioning - 1999 Full Ring** – Almost all magnet electrical system components were installed. Significant challenges getting all the systems integrated and interlocks & diagnostics working. The shunt power supply configuration was a significant challenge to get all the quad insertion region power supplies' current regulator stable. Main power supplies had issues that needed to be addressed. We also did this commissioning with record high outside temperatures. Look at the list of 73 items that needed to be addressed before the next run.
- **RHIC Run 1 - 2000 - First collisions occurred** – Still a significant number of magnet trips due to issues with ramping, hardware faults, quench detection programming and ground leakage current causing false quench signals. This is where we see that the environmental conditions in the tunnel has real impact on the electrical quench detector signals.
- **RHIC Run 2 – 2001** – Improvement still needed to software for power supply ramps & quench detection. Ground current leakage still causing problems with quench signals. Need more cold local voltage taps brought out to room temperature feed throughs. Improvement needed in DX quench detection software. Helical magnet integration and quench protection complexities.

RHIC Power Supplies, Quench Protection & Detection Systems, Early System Challenges - Summary

- **RHIC Run 3- 2002** – Run with d-AU showed problem with current imbalance of the Blue D0 shunt power supplies. The D0 exceeded the I_{mac} for the power supply DCCT. Solutions were implemented during the run. HDR102 had an internal cable failure. Magnet will be removed and repaired. Continued problems with leakage currents on quench detection voltage tap feed throughs. CQS magnet cryo lead flows must be checked. New quench interlock timing resolver system was installed which gave new diagnostic tool to find hardware faults.
- **RHIC Run 4 – 2003 – 2004** – The failure of HRD102 in the last run led to an extensive investigation on the cause for the failure. Two snake magnets were installed in SMD test facility and instrumented to determine a problem. The results of this was to have a new quench detection configuration with more signals to determine quench in this location of the HRD102. All snake rotators will require the new hardware and software. A more extensive solution to leakage currents on quench detector volt taps was implemented.