APPLICATION OF THE SUPERCONDUCTING POWER CABLES IN THE RHIC PROJECT[1]

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Abstract

The RHIC Project, now in construction at Brookhaven National Laboratory, is being constructed with superconducting power cables, known as the Cold Crossing Bus (CCBs), to make most of the connections between the power supplies and their magnet loads. This flexible, one inch diameter cable is installed in the helium transport pipes, and replaces much larger, more expensive, and less energy efficient conventional copper and tray systems.

First, the final design of the CCB and it's application in RHIC is reviewed. Then, experience gained with the completion of manufacturing and installation of the CCB cables is presented. Finally, test results and the use of the CCB in the first sextant test o RHIC will be discussed.

1 REQUIREMENTS

1.1 General

Several constraints lead to the development and application of the Cold Crossing Bus. Individually, each was nearly sufficient. Together, they were compelling.

The big detectors at RHIC consume most of the space between magnets at the crossing point. In addition, they need to roll out of position for maintenance and modifications. This requires the power to be routed out of the tunnel to connect to the magnets on the other side of the experimental area. This raises engineering challenges in using conventional copper cable:

- Large openings in the tunnel would be required for cable access. Aside from the construction cost, this would be difficult to provide shielding equivalent to that removed for the cable access.
- Long runs would result in power lost and require larger power converters.
- Material and installation costs would be high.

1.2 The Circuit

The connections that need to come out of the ring to cross the insertion region are very similar at all crossing points:

- Main magnets – Each ring has separate dipole and quadrupole circuits. While the power supplies for each of these circuits is 5500 amps, the dipole circuit crosses at the DX magnet, which can be boosted to 6300 amps. In addition, a 450 amp line carries the current offset between the horizontal and vertical quads.
- Shunting supplies – These supplies add or subtract current from the insertion dipoles (D0 and DX) and the insertion quadrupoles (Q1 through Q9). There are 16 of these circuits on each side of the crossing point, ranging in current from 100 amps to 2000 amps.
- Trim quadrupoles – These are twelve quadrupoles, each independently powered at up to 150 amps on each side of the crossing points.

All of these medium to high power circuits are routed to the service buildings using only four CCB cables (two per ring) on each side of the crossing point.

1.3 Warm Sections

At several places in RHIC, there are warm sections. There are warm sections of about 100 feet in every sector, between quadrupoles Q3 and Q4. Also, at the two injection regions, there are warm Lambertson and kicker magnets.

In all these areas, the beam pipe comes out of the cryostat, and the helium is bypasses the region using vacuum jacketed piping. The power circuits must also bypass the warm region, and this is done with Cold Crossing Bus.

2 CCB CONSTRUCTION

2.1 Construction Goals

There were several general goals for the construction the CCB:

- The currents in each cable sum to zero – This required that, as a minimum, each cable would have the main bus and all the shunting cables.
- Every superconductor in the cable would have a voltage tap conductor – This is needed to have a low noise voltage measurement for quench detection.
- The cable must be flexible enough to fit in a four inch diameter pipe with one elbow with a nine inch bend radius.
- The cable must be strong enough to be pulled through 350 feet of pipe without damage, and be

made of materials compatible with its cryogenic environment.

2.2 Final Configuration

In its final configuration, the CCB was configured into a one inch diameter containing the following conductors:

- Four 6300 amp conductors – These were used for the main bus connections and shunt supplies of 2000 and 600 amps.
- Three 450 amp conductors – These are used for the 450 amp shunts and the quadrupole offset current.
- Eight 150 amp conductors – These are used for the smaller shunts and quadrupole trim magnets.
- Seventeen copper voltage tap conductors – To monitor the superconductors for quench detection.

This entire assembly was jacketed in a layer of Kapton, then Mylar, and finally a copper braid.

2.3 Manufacturing

The manufacturer and development partner for the CCB was New England Electric Wire and Cable, Lisbon, NH, USA. As the CCB is a melding of both superconducting and conventional construction techniques, the vendor must have considerable expertise in both areas. In-process testing of the superconductor cables included sending short samples back to BNL for testing prior to completing the cable assembly. Yet, at other stages, manufacturing was quite similar to conventional cable.

Approximately 30,000 feet of CCB was manufactured, and several lessons were learned in the process. For example, the outer jacket was originally woven Nomex [1]. But test pulls in cryogenic pipe showed that the strands of Nomex tended to fray. While this fraying was not a problem to the cable, it could have clogged the cryogenic filters. Changing to the copper braid did not make the cable significantly stiffer, and the fraying problem was eliminated.

3 INSTALLATION

Pulling the CCB into the vacuum jacketed piping at a crossing point could be accomplished in a single day. This is in contrast to an equivalent system of conventional copper cables, where first a tray system would need to be installed, and then the pulling of the hundreds of cables could begin.

The cryogenic piping was installed in sections. Prior to the CCB being installed, the gaps between the sections were left open. Then, the two CCB cables were pulled simultaneously over the entire length with workers also pulling at the gaps for longer runs. The cable is left with slack in the pipe, and no other support along the entire length of the pipe.

4 TESTING

4.1 Quench Properties

The quench properties of the CCB were tested by inducing quenches with spot heaters. Doing this, several parameters can be determined.

The Miits (Million i2*t) rating is a measure of how much energy the cable can absorb during a quench, without damaging the insulation materials or solder joints. In designing the cable, a very conservative method of estimating the performance is used, which does not include cooling effects. Using that method, sufficient stabilizing copper was added to the main conductors for a Miits rating of 208. Measured data showed the actual rating to be 325.

Quench propagation time, which gives an indication of how long it will take us to detect a quench. Knowing how long the quench will take to detect, and it's Miits rating, determines allows the energy extraction time to be found. The quench propagation time was measured at 12 inches per second.

Bus to bus propagation time is a measure of how long it takes a quenched conductor to cause a quench in an adjacent conductor. Knowing this helps localize quenches for short conductors. This was measured to be 4 seconds at 5500 amps.

4.2 Installed Cable Testing

There have been two major tests of installed cable. The first was a cryogenic distribution test. Coolant was circulated from the refrigerator to the service building at the 6:00 crossing point, and down to the ring. During this test, 6300 amp conductors were powered to 7000 amps, with no quenches.

The most extensive test of the cable to date has been the sextant test. For that test, CCB was installed at two service buildings, and in the piping that bridged the warm sections between them. When there was no beam in the ring, the main supply ramped up the current to it's limit of 5500 amps. This test was repeated hundreds of times with no quenching of the CCB.

5 ACKNOWLEDGEMENTS

The author would like to thank G. Ganetis and J. Muratore of the RHIC Project, who devised and performed the tests, and analyzed the data that was included here.

REFERENCES

[1] R. F. Lambiase, "Superconducting Power Cables in the RHIC Project", EPAC'94, London, UK, June 1994.