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HEAT LEAK TESTING OF A SUPERCONDUCTING RHIC DIPOLE MAGNET AT BROOKHAVEN NATIONAL LABORATORY *

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ABSTRACT

Brookhaven National Laboratory is currently performing heat load tests on a superconducting dipole magnet. The magnet is a prototype of the 360, 8 cm bore, arc dipole magnets that will be used in the Relativistic Heavy Ion Collider (RHIC). An accurate measurement of the heat load is needed to eliminate cumulative errors when determining the RHIC cryogenic system load requirements. The test setup consists of a dipole positioned between two quadrupoles in a common vacuum tank and heat shield. Piping and instrumentation are arranged to facilitate measurement of the heat load on the primary 4.6 K magnet load and the secondary 55 K heat shield load. Initial results suggest that the primary heat load is well below design allowances. The secondary load was found to be higher than estimated, but remained close to the budgeted amount. Overall, the dipole performed to specifications.

INTRODUCTION

The RHIC accelerator contains 1740 superconducting magnets. These magnets form two concentric rings approximately 3.8 km in circumference. Cooling a machine of this magnitude requires a big refrigerator and an extremely efficient insulation system. The RHIC arc dipole magnet represents a five-year effort in combining superconducting magnet and cryogenic insulation technologies. Every RHIC magnet will employ the same design of support posts, heat shield, multi-layer insulation, and outer vacuum jacket as the dipole. The RHIC Cryogenic Test Facility (CTF) was recently commissioned to test various components starting with the dipole. The results obtained are critical to the collider's performance.

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SYSTEM DESCRIPTION

RHIC dipoles were designed to meet the heat load budget given in Table 1 The magnet will be cooled by 4.6 K, 5 atm (0.5 MPa) supercritical helium flowing at 100 g/s. Under these conditions the temperature rise across the magnet is expected to be roughly 6 mK. This small rise is extremely difficult to measure. The CTF is designed to deliver supercritical helium at flow rates under 1 g/s. The low flow rate increases the temperature rise allowing for a more accurate measurement of heat load.

Table 1. Heat Load Allowance per 9.7 m Arc Dipole. Source: RHIC Design Manual (July 1992)

Item	Primary Watts @ 4.6 K	Secondary Watts @ 55 K
Total Support System	0.30	3.24
Insulation - Radiation & Conduction	1.69	12.70
Interconnect Insulation	0.22	6.80
Other	0.30	2.00
Total for Dipole	2.51	24.74

Table 2. Calculated Heat Load per 9.7 m Arc Dipole.

Item	Primary Watts @ 4.6 K	Secondary Watts @ 55 K
Total Support System	0.30	3.24
Insulation - Radiation & Conduction	1.12	5.40
Interconnect Insulation	0.11	3.50
Other	0.00	0.00
Total for Dipole	1.53	12.14

One important aspect of measuring the heat load on a superconducting magnet is eliminating end effects. Previous tests have been plagued with poor results caused by radiation shine and conduction down interconnecting piping at the magnet ends. Two quadrupoles were added to the CTF test setup to eliminate end effects, add a thermal buffer before and after the dipole, and allow the system to accurately reflect the final ring configuration. A schematic of the test setup is shown in Figure 1.

The magnets used for this test were originally used in the first RHIC string tests. They are identical to the final production units except for modifications to the ends. To simplify the system, there is no beam tube, instrumentation wire, or interconnecting superconducting cable. The magnets are essentially iron cold masses with end volumes resembling the interconnect. All other aspects of the magnets including the support posts, multi-layer insulation, heat shield, and outer cryostat are identical to the final design.

Heat load is calculated by taking the difference in inlet and outlet enthalpy and multiplying it by the mass flow rate. Helium mass flow is measured warm by a Hastings Model HFM mass flowmeter. The calibrated range is 2 g/s with accuracy of plus or minus 1% of full scale. Enthalpy is taken from the NBS Tables for corresponding pressure and temperature readings.[1] The test is run at approximately 11 atm (1.1 MPa), which is higher than the 5 atm (0.5 MPa) nominal operating pressure. This is done because helium's specific heat is much more constant at higher pressures. A slight variation in pressure will not change the gas properties substantially.

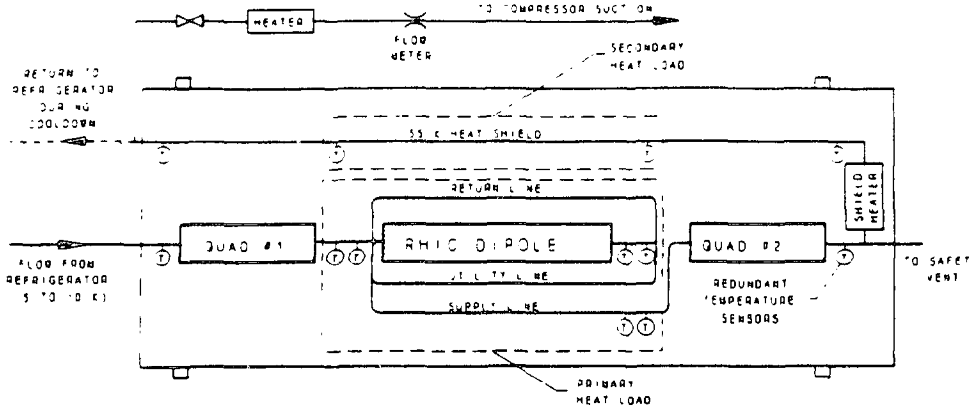

Figure 1 - Schematic of test setup

Accurate temperature readings are essential to heat load measurements of this type. Helium enthalpy is inherently sensitive at low temperatures. For this reason, the CTF system uses redundant pairs of silicon diode and carbon glass sensors. Sensors are factory calibrated to an accuracy less than 12 mK under 10 K, and are mounted in the helium flow to allow for good thermal sinking. Temperatures are calculated by the new RHIC temperature acquisition system. Errors in sensor reading are less than 1 mK under 10 K.[2]

The thermal gradient around the heat shield is also measured during CTF heat load tests. Silicon diodes are mounted radially on the shield at each dipole support post. See Figure 2 for a detailed cross section of the magnet and sensor locations.

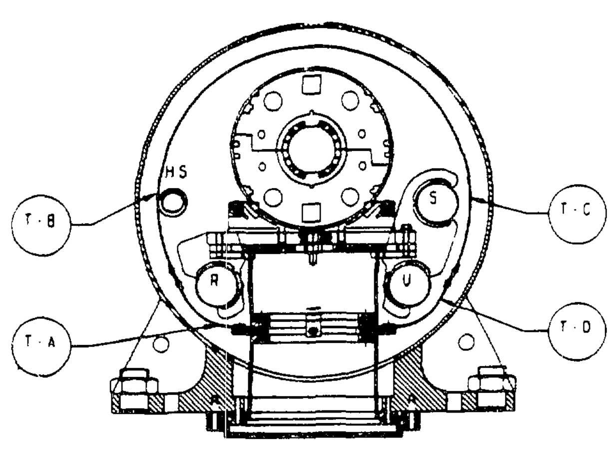

Figure 2 - Magnet cross section.

TEST RESULTS

Table 3. Test Conditions July 5, 1993 to July 7, 1992.

Duration of Test Run	50 Hours
Average Flow Rate	0 41 g/s
Average Pressure	10 99 atm
Average Inlet Temp	8 35 K

Primary Heat Load Calculation

Initial results suggest that the dipole is performing well within the RHIC cryogenic system allowances. The maximum load in a 50 hour period was only 1.66 W, with an average of 1.24 W. These results are less than budgeted and extremely close to calculated values. Although there is a slight fluctuation, the heat load was fairly constant over the run (see Figure 3). The variation is mostly explained by the changes in inlet temperature and pressure. It is not surprising that temperature and pressure wander considering over 6000 kg of iron and 45 L of volume is being cooled by 0.4 g/s of helium. As Figure 3 and 4 indicate, the fluctuations were following a cyclical pattern which appeared to be dampening. Unfortunately, the test run was prematurely ended.

Table 4. Summary of heat loads results.

	Measured Heat Load (W)		
	Average	Maximum	Minimum
Dipole -Magnet	0.828	1.205	525
Dipole - Piping	0.411	.519	0.201
Dipole - Total ** Primary Load	1.239	1.664	.892
Dipole - Shield Secondary Load	25.60	26.58	24.28
Quad #1 - Magnet	0.383	0.553	0.230
Quad #1 - Shield	13.73	13.97	13.48
Quad #2 - Magnet	7 818	8.963	7.089
Quad #2 - Shield	12.11	12.61	11.60

** - Values calculated from state properties not max and min

A discrepancy exists in the measured quadrupole heat load. Although the two magnets are identical, the load differed by 7.44 W. While quadrupole performance is not the focus of this study, an explanation is warranted. The outlet temperature sensor to quadrupole #2 is located approximately 20 cm from the inlet to the shield heater.

Although data is not available at this time, when the heater was not energized the quadrupoles had similar heat loads. Most likely, the outlet sensor was warmed by heat from the heater via conduction.

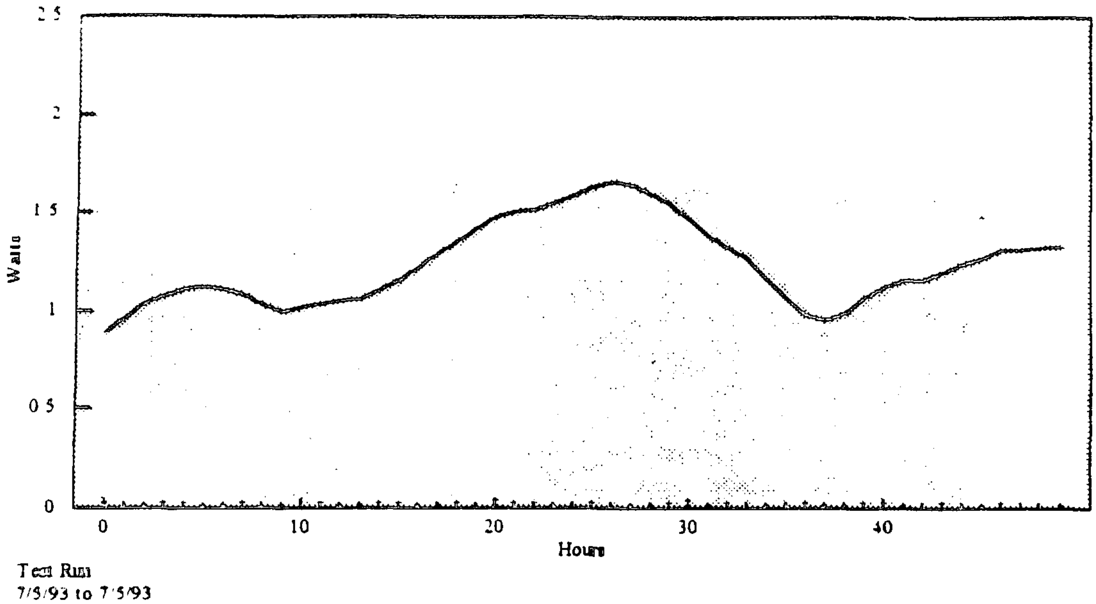

Figure 3 - Primary heat load vs time (dipole magnet and piping).

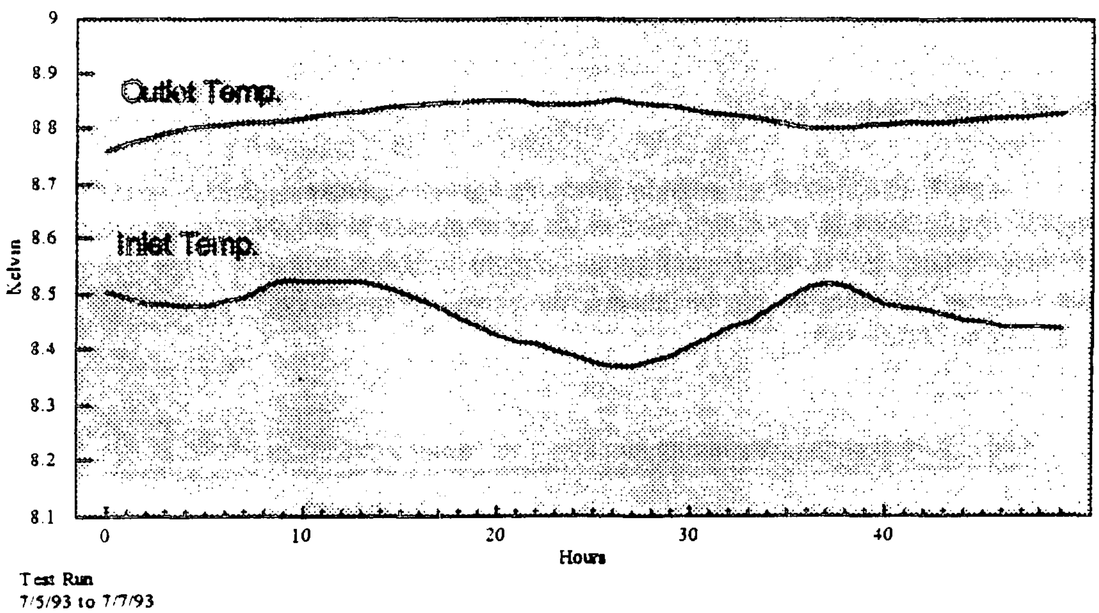

Figure 4 - Dipole inlet and outlet temperature vs time.

Secondary Heat Load Performance

The heat load on the 55 K heat shield was higher than expected. It averaged 25.6 W with a maximum of 26.6 W These values are only slightly higher than system allowances which is not a serious problem. However, they are almost double the calculated values. One reason for a high load could have been inadequate insulating vacuum If this is the case, the shield was intercepting a much greater load than normal The vacuum pump pressure measured 1 X 10^{-6} mm/Hg during the run However, this is not necessarily the pressure within the cryostat.

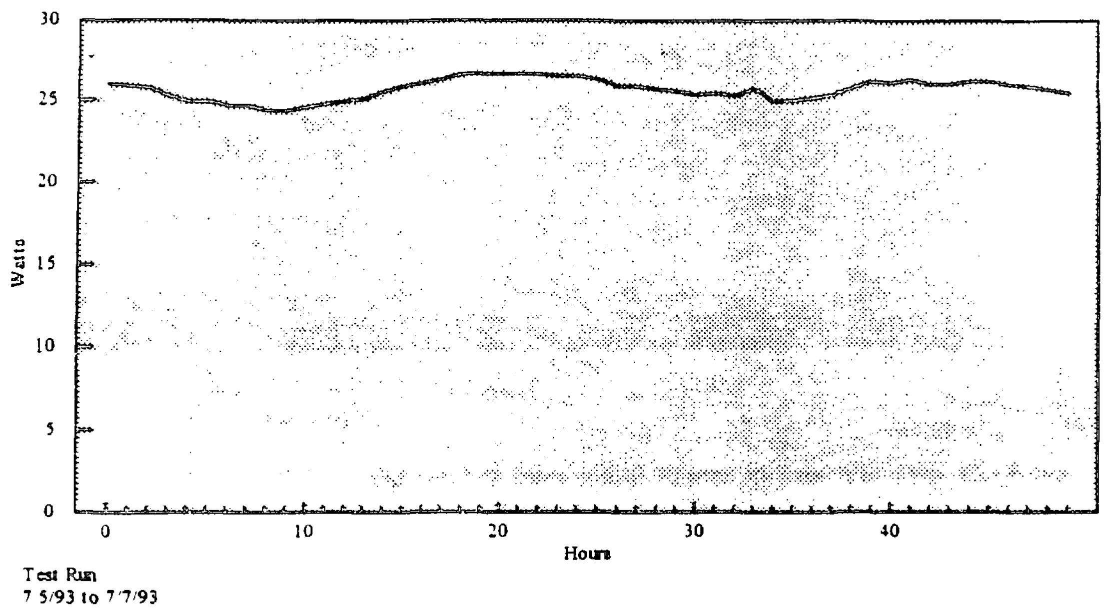

Figure 5 - Secondary heat load vs time (55 K heat shield).

Heat Shield Thermal Gradient

The heat shield had a fairly uniform temperature around its circumference. As expected, the highest temperature was at the connection to the magnet support plate and the lowest next to the shield supply pipe. Despite the high heat load and large temperature differential across the shield, the shield temperature profile remained fairly constant (see Figure 6.).

Table 5. Heat shield temperature (see Fig. 2 for sensor location).

	Temperature (K)		
Location	Dipole Outlet	Dipole Midpoint	Dipole Inlet
A	68.23	65.47	***
B	66.37	64.40	62.65
C	66.83	64.79	63.53
D	67.11	65.08	63.77

*** Sensor not in operation

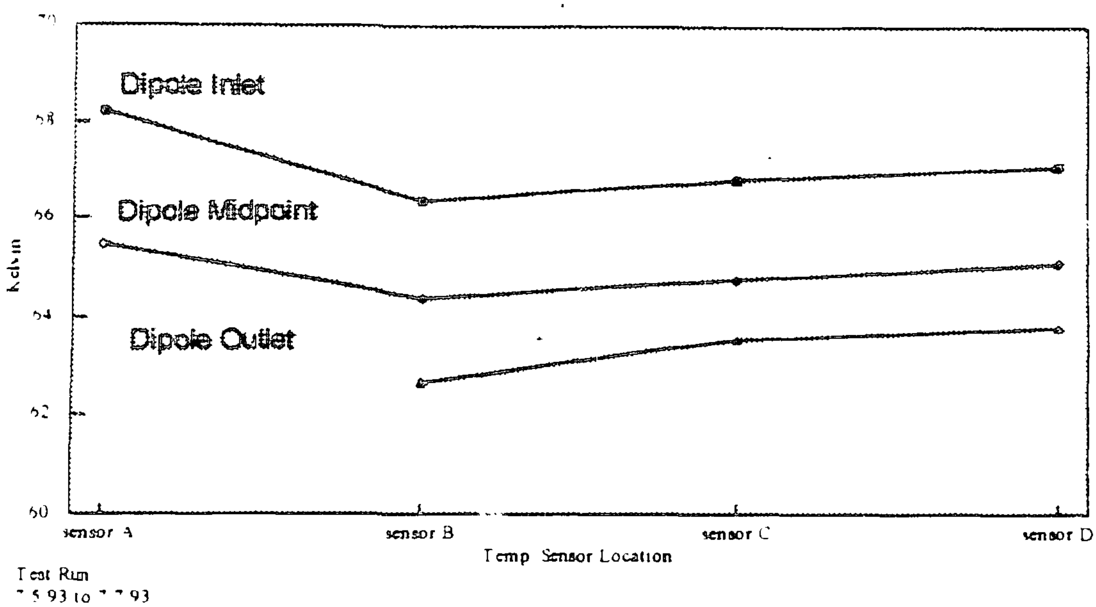

Figure 6 - Heat shield temperature distribution

CONCLUSION

The results obtained in this initial run are very encouraging. Heat loads are close to expected and fairly constant. This indicates there are no major problems with the dipole insulation and support system design. However, RHIC Cryogenics plans to run several more tests on the dipole. Preliminary testing plans call for longer test runs, at different pressures, and with different mass flow rates. The high heat shield load will also be studied in greater detail. After the dipole, two RHIC CQS quadrupole magnets are scheduled for testing.

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