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Comparison of Total Cooling Provided to the Energy Released After Low Current Quenches of SSC Dipoles in MAGCOOL

K. C. Wu

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Collider Accelerator Department

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K. C. Wu

RHIC Project, Brookhaven National Laboratory
Upton, New York 11973-5000

ABSTRACT

The performance of the MAGCOOL cryogenic system after low current strip heater quenches of SSC dipole has been investigated. For quench currents between 2000 and 4000 amperes, the loop pressure after a quench does not exceed the set pressure for venting. Excellent agreement between total cooling and the magnetic stored energy is found for each of the several values of quench current. The results indicate that the measurements are accurate and the method of calculation appropriate.

INTRODUCTION

The performance of the MAGCOOL-Subcooler cryogenic system after 50 mm SSC dipole magnet quenches in the operating current range from 6000 to 8413 amperes has been previously investigated and reported[1]. The cooling/heating and venting mechanisms of the system have been illustrated. Total cooling provided during quench recovery has been calculated. The comparison of total cooling to the magnetic stored energy is quite good for the 6000 ampere quench, but is only fair for the higher current quenches. The discrepancy is believed to be caused by the venting effect which is neglected in the calculation of enthalpy flux.

Since the piping system is designed for 300 psi, helium must be vented whenever the loop pressure approaches the design value. One way to prevent the vent valve from opening is to reduce the current at which the magnet is heater quenched, and therefore the energy released into the system, so that the peak loop pressure after the quench is below the set value of the valve for venting.

Strip heater quenches for DCA209 at 2000 amperes, and DCA210 at 2000, 3000 and 4000 amperes have been performed. Pressures, temperatures and flow rates are given as functions of time. The apparent cooling rate applied to the magnet has been calculated. The total amount of cooling for quench recovery has been evaluated. Comparisons between total cooling and the magnetic stored energy are given for the several currents.

PRESSURE, TEMPERATURE AND FLOW RATE AFTER QUENCH

The following results were obtained from quenches of the SSC DCA210 dipole in MAGCOOL test stand A. The magnet is maintained at 4.3 K prior to a quench. Quenches are initiated at 2000, 3000 and 4000 amperes by a strip heater located on the outer coil of the magnet. The corresponding magnetic stored energies are 163, 367 and 652 kilo-joules.

The loop pressures as a function of time are given in Fig. 1. As can be seen, the peak pressure increases with the amount of energy released. The peak pressures are 7.8, 14.1 and 17.5 atm, occurring at 29, 41 and 48 seconds respectively after the quench, for quench currents of 2000, 3000 and 4000 amperes. Because the amount of energy released into the system is small relative to the cooling stored in the precooler and subcooler helium pots, the loop is cooled down quickly and the pressure is back to 5 atm in about 5 minutes.

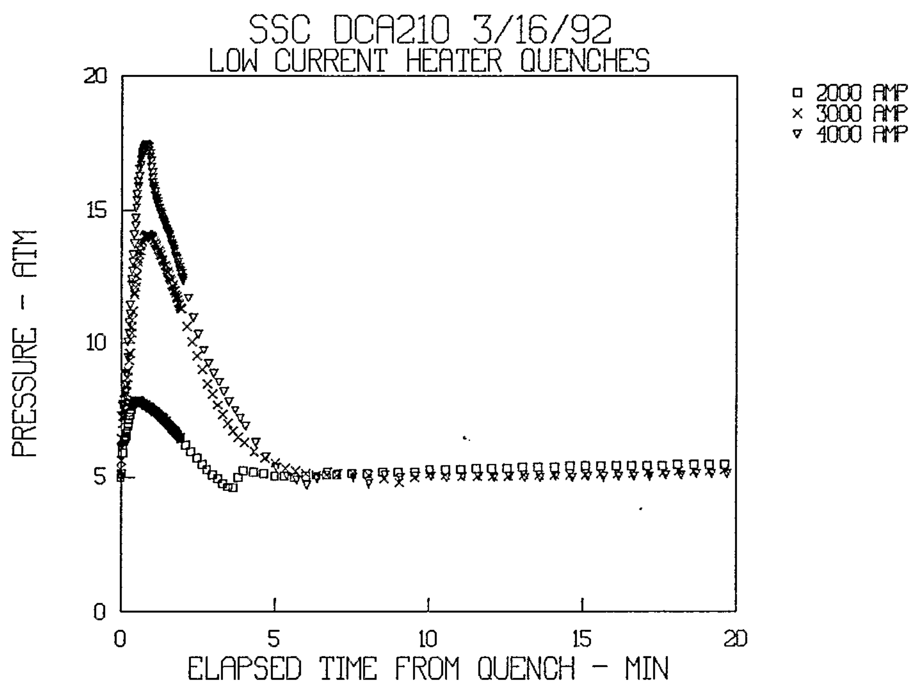

Fig. 1 Loop pressure after magnet quenches

Temperatures recorded at the return and supply lines of the subcooler assembly are given in Fig. 2 and 3. The return temperatures are higher for higher current quenches. The peak temperatures recorded are 5.72, 7.16 and 9.46 K, occurring at 120, 126 and 119 seconds respectively after the quench, for the 2000, 3000 and 4000 ampere quenches. The differences between the peak return temperatures and the 4.3 K test temperature prior to a quench are 1.42, 2.86 and 5.16 K. These temperature differences represent characteristically the amount of energy absorbed by the loop and are roughly in proportion to the energy released by the magnet. The times at which the peak temperatures were recorded depend primarily on the circulation of helium flow rather than the stored energies, and are approximately 2 minutes after a quench for all cases. Since recovery of temperatures in the loop depend on the circulation of helium, the loop temperatures do not return to their original values as quickly as the loop pressures.

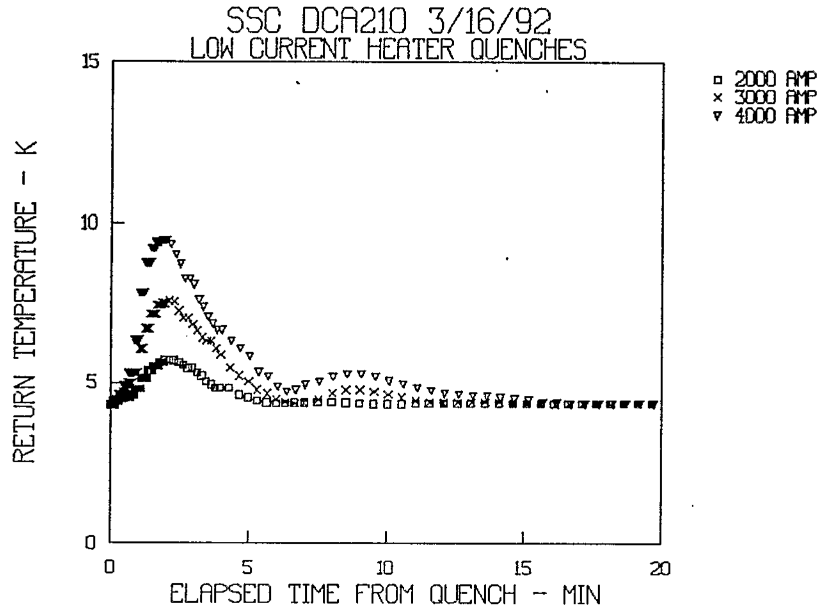

Fig. 2 Return temperature of the subcooler after quench

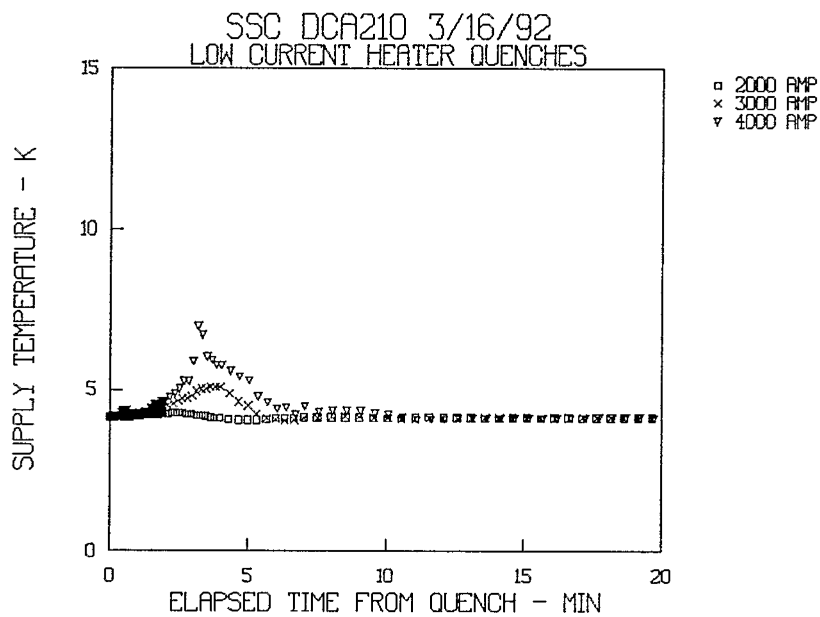

Fig. 3 Supply temperatures of the subcooler after quench

The helium flow through the magnet as a function of time is given in Fig. 4. The mass flow rate after a quench first increases due to an increase in loop pressure but soon decreases as the return temperature which is seen by the circulating compressor increases. As expected, a lower current quench corresponds to a smaller perturbations on the flow rate because the perturbations on pressure and temperatures are smaller.

The lowest flow rate occurs when the peak temperature reaches the circulating compressor. As the temperature at the circulating compressor decreases from the peak value, the mass flow rate increases until it reaches its original value.

The flow rate is a good indicator of the recovery of the magnet loop. For the 2000, 3000 and 4000 ampere quenches, the recovery times are about 6, 13 and 17 minutes. Total system recovery includes the recovery of the magnet loop and the liquid levels in precooler and subcooler helium pots.

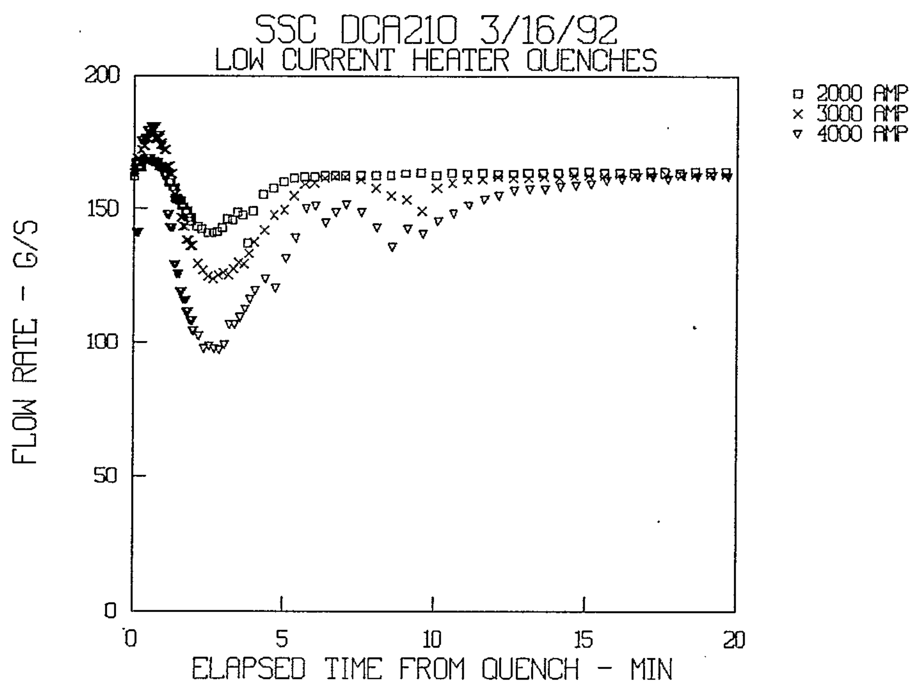

Fig. 4 Mass flow rate after magnet quench

COOLING RATE AND TOTAL COOLING

The apparent cooling applied to the magnet is defined as the difference of enthalpy flux between the supply and the return lines. The net cooling for quench recovery equals the apparent cooling rate minus the background heat load. Because the system which started at test condition is cooled to the original condition after a quench, the integration of the net cooling rate represents the total amount of cooling provided for quench recovery and should be equal to the stored energy released by the magnet.

The apparent cooling rates during quench recovery are given in Fig. 5. The apparent cooling rate peaks at 0.91, 2 and 3 kilo-watts for quench currents of 2000, 3000 and 4000 amperes respectively. The peak apparent cooling rate is not directly in proportion to the energy released since the supply temperatures were not the same for the 3000 and 4000 ampere quenches.

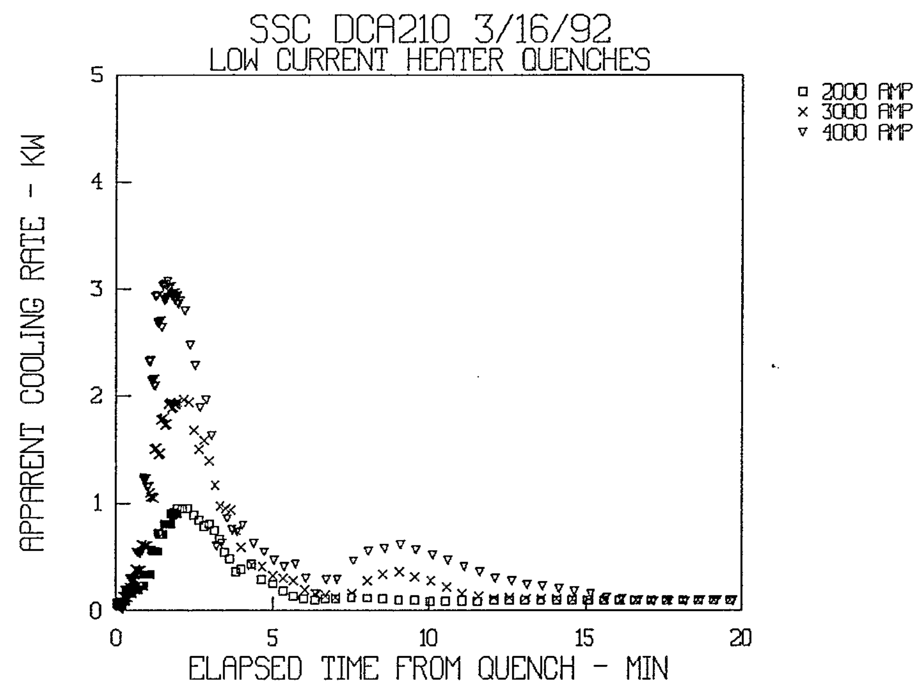

Fig. 5 Apparent cooling rate during quench recovery

Total cooling provided during quench recovery for the 2000, 3000 and 4000 ampere quenches is given in Fig.6. The cooling provided increases with time and reaches a plateau when the loop is cooled to conditions existing prior to the quench. The total cooling provided is found to be 160, 389 and 656 kilo-joules for the 2000, 3000 and 4000 ampere quenches respectively.

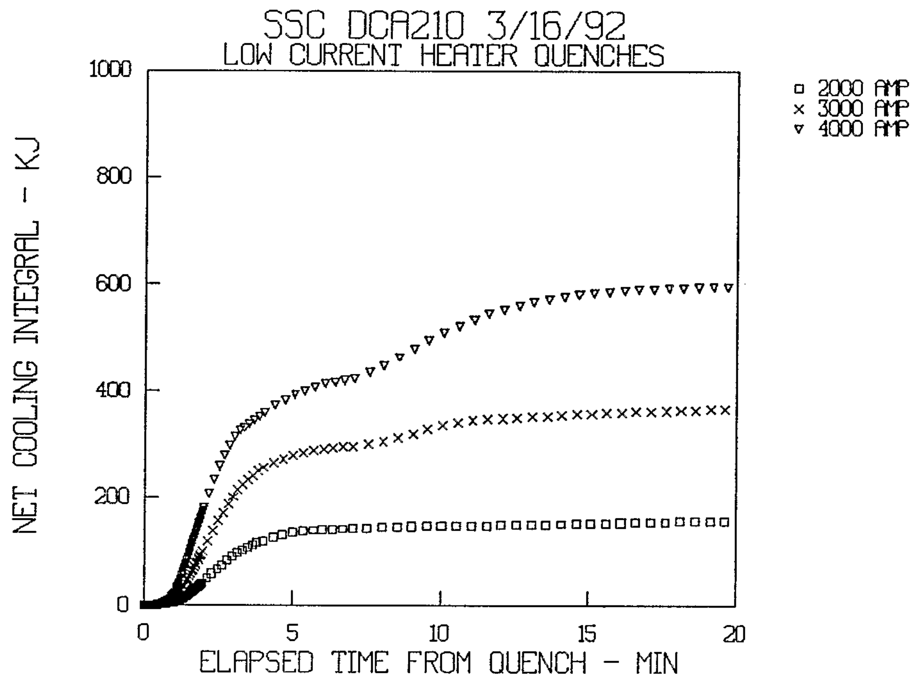

Fig 6. Total cooling provided to the magnet

Key parameters for the low current quenches and the corresponding stored energies are summarized in Table 1. In Table 1, the recovery time refers to the time liquid levels in the helium pots are restored. The ratios of total cooling provided to the magnetic stored energy are found to be 0.88, 0.98, 1.06 and 1.01 for the several values of quench current.

Table 1. Results of the low current quench

Magnet	Quench Current	Peak Pressure	Time to Peak Pres.	Peak Return Temp.	Time to peak Temp.	Max. Cool-ing rate	Total Cool-ing	1/2 LI^2	Ratio	Recovery time
	ampere	atm	sec	K	sec	kw	kj	kj		min
DCA209	2000	8.5	29	5.7	135	.92	143	163	0.88	7
DCA210	2000	7.8	29	5.7	120	.91	160	163	0.98	9
DCA210	3000	14.1	41	7.6	126	2	389	367	1.06	15
DCA210	4000	17.5	48	9.5	119	3	656	652	1.01	20

CONCLUSION

The results given in this paper clearly show excellent agreement between the cooling provided and the energy released in the absence of venting. Even though the thermodynamic process following the magnet quench is complex and transient, the thermal fluid measurements are accurate. Since the magnet system which is at a given test condition before a quench is recovered to that condition after the quench, the magnetic energy released during the quench can be calculated by the integration of the net cooling rate over the interval of time from the initiation of the quench to the restoration of the conditions existing in the cooling loop prior to the quench.

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REFERENCES

1. K. C. Wu, "Performance of the MAGCOOL-Subcooler Cryogenic System After 50 mm SSC Dipole Quenches", RHIC Project Technical Note, AD/RHIC/RD-37, Brookhaven National Laboratory, 1992.