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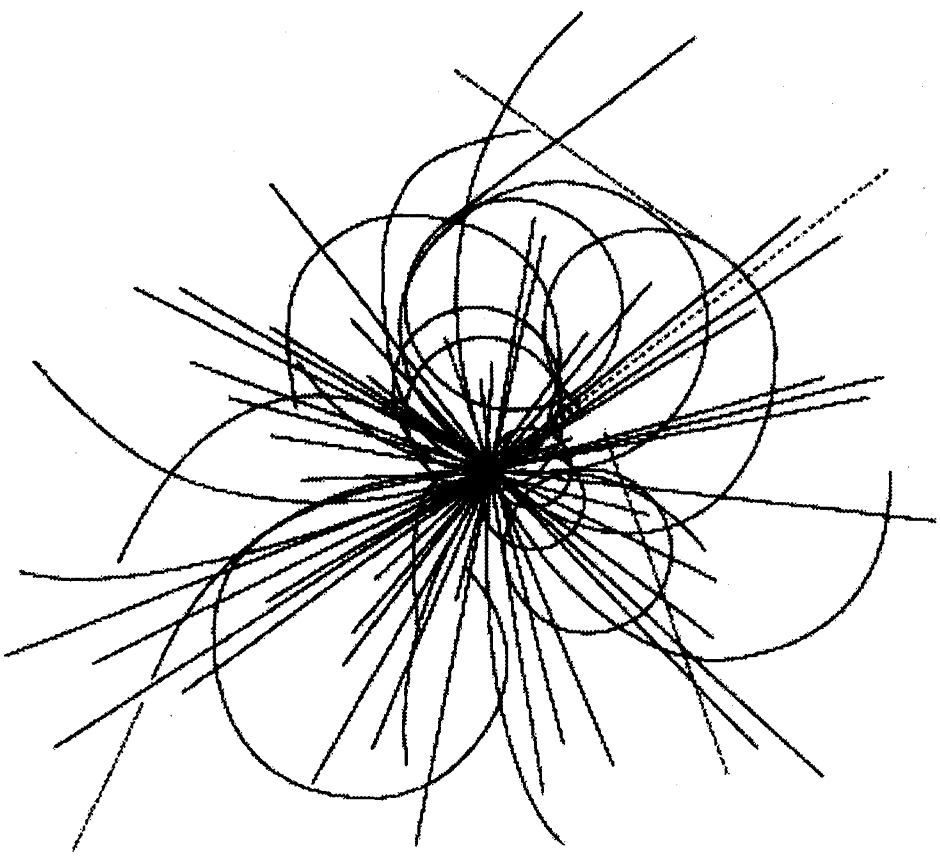

Superconducting Super Collider Laboratory

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REDUCING THE ENERGY REQUIREMENTS OF QUENCH PROTECTION HEATERS FOR SSC DIPOLES - TEST RESULTS

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INTRODUCTION

Design considerations and first test results of quench protection heaters for Superconducting Super Collider (SSC) collider dipole magnets have been presented in earlier papers.[1,2]

The heaters have been shown to fully protect the magnet against excessive peak temperatures which would represent damage to the superconducting coil. Installation and operation of the heaters does not place the magnet at any increased risk of failure, since the energy densities applied are relatively low (~ 1J/cm^2) and the construction technique was made as simple as possible.

The energy required by the heaters in order to protect the magnet is considerably larger than that amount estimated during the planning of the collider ring protection scheme. Therefore, three long magnets following the Accelerator Systems String Test (ASST) construction series at Fermi National Accelerator Laboratory (FNAL) were made available for quench protection heater "R&D" studies. All of the ASST series magnets deliberately kept the high energy requirement heaters for the purpose of commonality for the string test.

This paper describes the results of the "R&D" heater tests and the amount of energy reduction achieved. It is shown that it has been possible to reduce the heater energy requirement to a value below the original estimate, and to therefore potentially save collider cost.

SOURCES OF ENERGY INCREASE

The first full length ASST 50 mm aperture dipole magnet built and tested at FNAL (DCA311) incorporated a number of changes from the 40 mm program which affected quench heater energy requirements. First, a second layer of Kapton 5 mil (0.127 mm) in thickness, was added between the quench heater and the superconducting coil, intended to reduce the risk of a heater to coil short. In order that the required quantity of heat to quench the magnet be conducted across the insulation thickness in the required time, (200ms @ 2,000A) a larger energy pulse was now needed at the quench heater terminals.

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Secondly, the operating margin of 50 mm dipoles was designed higher than that for the 40 mm dipole program. In order to quench the magnet in a given time interval, an extra amount of energy was required.

Thirdly, it was required that the quench protection heaters should have a cold resistance value of the order of 10 times that of a previous spot like heater design. This is required such that in the collider ring most of the energy from the heater firing unit (HFU) is deposited into the quench heater and not into the connecting leads between the HFU and the magnet. These connecting leads can be quite long (~ 300m). This in turn required that the quench heater should be essentially a long stainless steel strip along the length of the magnet. The strip has been partially copper plated in order to meet the cold resistance requirements. The active area of the strip is approximately 50 times the spot heater type design; its area was chosen to be conservative since it was hypothesized that the quench propagation velocity in 50 mm magnets might be slower than that for the 40 mm case and, therefore, that a larger coil volume would need to be quenched by heaters in order to protect the magnet. This in turn would require a higher heater energy.

R&D MAGNET HEATERS TEST RESULTS - HEATER ENERGY REDUCTION

T_fn is the characteristic response time interval of the quench heaters. It is the time interval between firing of the quench heater unit and the development of a normal resistive region in the coils. It has been typically shown that T_fn = 200/100ms is sufficient to protect a magnet when operating at a current of 2000A/5000A.

The heater energy increase due to the larger operating margin of 50 mm dipoles was measured in the following way. The energy/unit area of quench heater required to produce a T_fn=200ms @ 2000A was measured on short 40 mm dipole DSO313. All of the quench heaters in this study have the same thickness (0.025mm) and width (12.7mm). The experiment was repeated on short 50 mm magnet DSA328 which had been built with one set of heaters placed one layer of 0.127 mm Kapton from the coil. The results are shown in Table 1.

It was also possible to determine how much extra energy was required due to the second layer of Kapton in DSA328, where a second set of heaters was placed two layers of 0.127mm Kapton from the coil. The results are also shown in Table 1 and Figure 1.

Table 1. Increased heater energy requirement due to increased margin and increased insulation thickness.

Magnet Current (A)	T_fn (ms)	DS0313 (40mm) 1 Layer Kapton	DSA328 (50mm) 2 layers Kapton	DSA328 (50mm) 1 layer Kapton
2000	200	0.43 J/cm^2	1.47 J/cm^2	0.77 J/cm^2

The required energy increase due to the increased operating margin is 80%. It can be seen also from Table 1 that the required energy increase due to the second layer of Kapton represents a factor of 1.9 over the case for one layer of Kapton. Since the risk of heater-to-coil shorts had been mitigated by improvements in the heater design itself, it was not necessary to also include an extra layer of Kapton in the design, after the ASST (DCA311- DCA320) series was completed. The first full-length magnet "R&D" test was to place a so-called "baseline" heater set one layer of 0.127mm Kapton from the coil, and compare it with another set placed two layers from the coil., i.e., to repeat the DSA328 experiment on a full length magnet. The reduction in heater energy was by a factor of 2.3 times. This energy reduction has been since incorporated into the baseline design of the collider ring dipoles.

On the succeeding two R&D full-length magnets (DCA322 AND DCA323), all quench heaters were placed one layer of 0.127mm Kapton from the coil. These two magnets studied the effect of reducing the "active area" i.e., the unplated length of the quench heater.

Magnet DCA322 contained one set of baseline heaters and one "R&D" set on which the active area had been reduced by a factor of 6 compared to the baseline. On magnet DCA323 the active are was reduced by a factor of 12. The results for magnet DCA311, which contained two sets of baseline heaters placed two layers from the magnet coil, are compared to the results for magnets DCA322 and DCA323 in Figure 2.

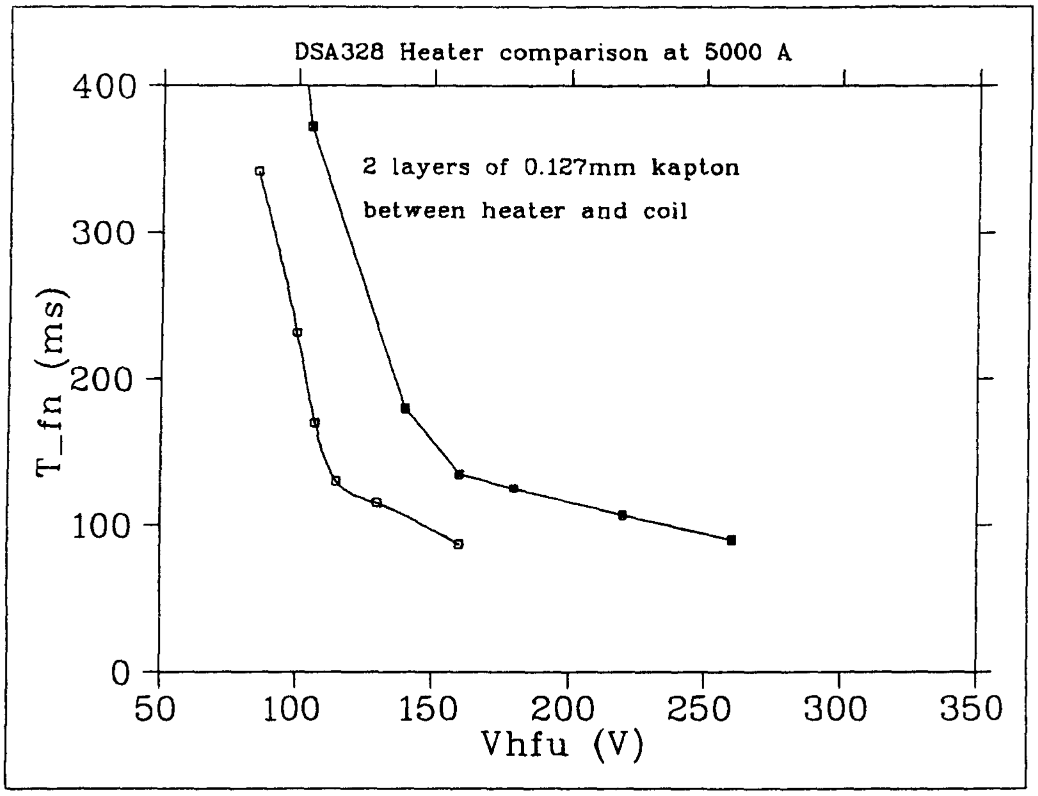

Figure 1. T_fn vs HFU Voltage comparison for quench heaters placed one and two layers of 0.127mm Kapton from coil. The reduction in HFU voltage represents a factor of 1.9 in Energy.

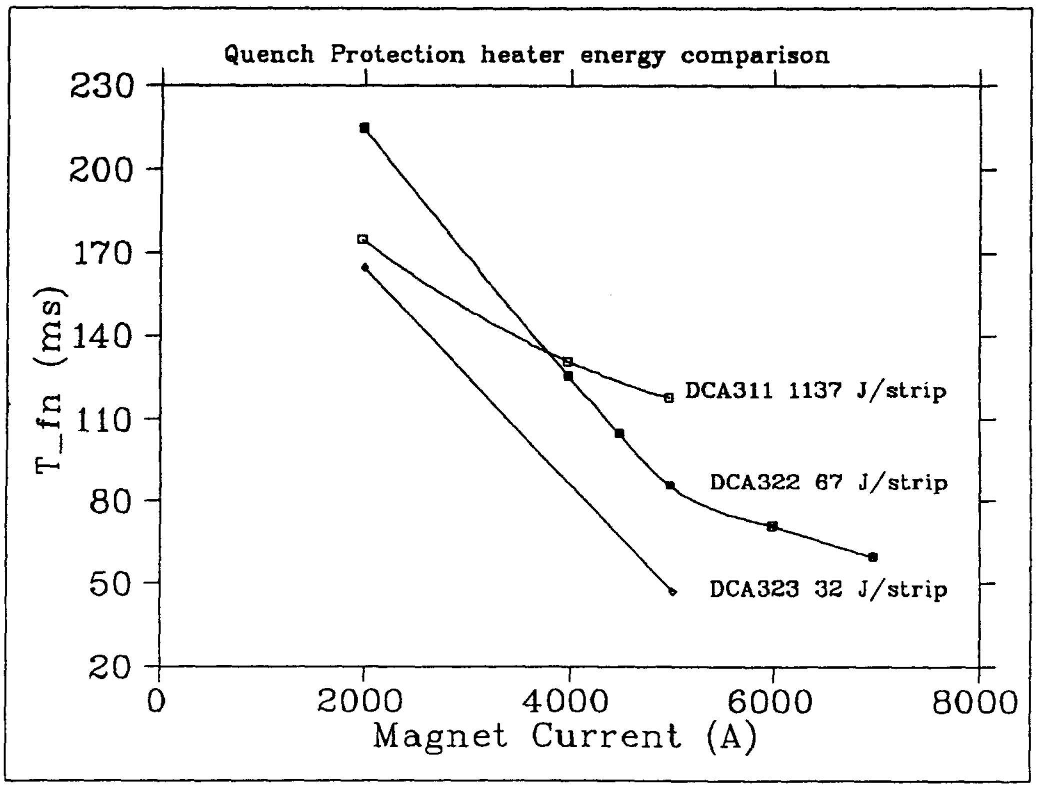

Figure 2. Quench Protection heater energy reduction on three full-length dipoles.

The performance is similar in each case. The "R&D" heaters protect the magnet with 1/17th and 1/35th the value of energy of the DCA311 tests for magnets DCA322 and DCA323, respectively. The energy required (67 J or 32 J for DCA322 and DCA323 respectively) is now considerably less than the original estimate used for evaluating HFU costs for the collider.

FUTURE STUDIES

The reduction in quench protection heater energy by reducing the active length of the heaters also involves decreasing the resistance of the heater. This in turn results in a higher loss in the connecting leads to the HFU. However the reduction in energy achieved is such that the energy loss increase in the leads is tolerable. The cost of the quench heaters is essentially the same regardless of their plated length since they are simply plated strips of stainless steel in a Kapton insulation. However, the cost of the connecting cable, capacitor cost, cabling tray cost, HFU niche size and number, may greatly depend upon the value of the quench heater resistance, and further may experience sharp trends as one finds it necessary to move to non-standard sizes of capacitor, cable tray, etc. Since the performance of the quench heaters of different active length and resistance is now well known, it is possible to optimize the rest of the components of the collider protection electronics with respect to overall cost. Based on the provided quench heater performance data, this task will be performed by the Accelerator Division, Electrical Department of SSCL [1]. This will, in turn, allow a statement of the necessary quench heater resistance to minimize the cost of the collider protection scheme.

SUMMARY

Through a series of tests on three dipole magnets, it has been possible to reduce the energy required by quench protection heaters by a factor of 17, while maintaining the same magnet protection.

REFERENCES

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