SSCL-Preprint-244

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May 1993
Distribution Category: 414

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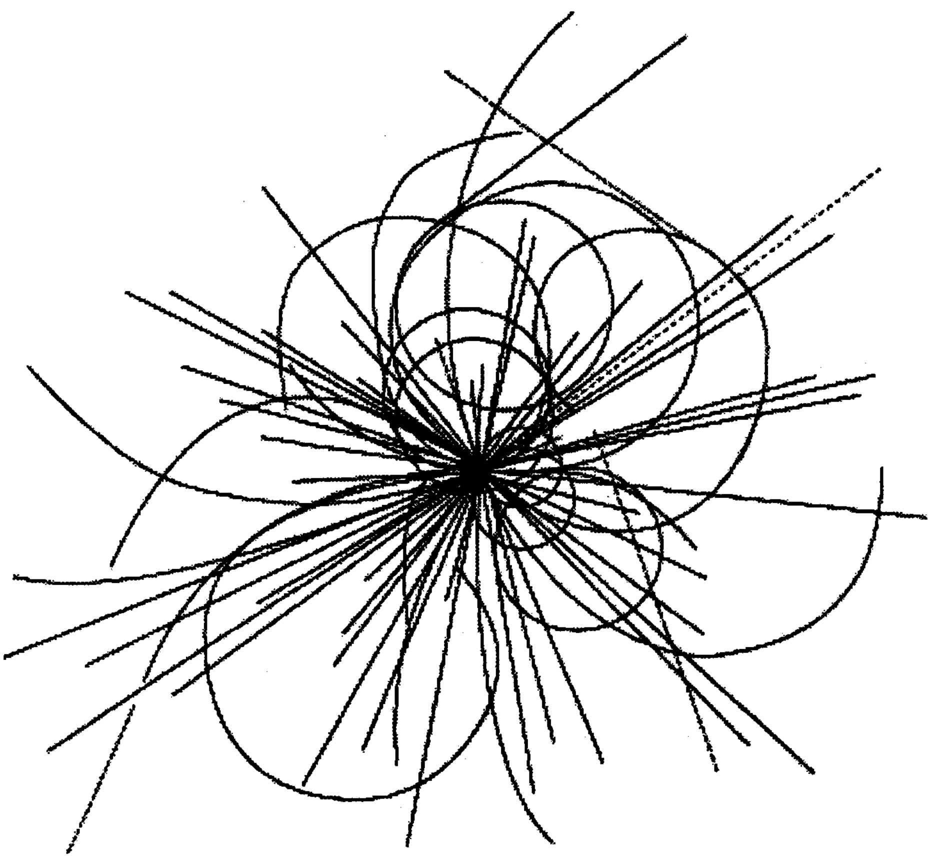

Superconducting Super Collider Laboratory

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Quench Simulation of the 40 mm Aperture SSC-Quadrupole Magnet Connected in Series with 50 mm Aperture SSC-Dipole Magnets*

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May 1993

* To be presented at the 1993 IEEE Particle Accelerator Conference on May 17–20, Washington, D.C.

† Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Quench Simulation of the 40 mm Aperture SSC-Quadrupole Magnet Connected in Series with 50 mm Aperture SSC-Dipole Magnets

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Abstract

The hot-spot temperature is estimated for a Collider Quadrupole Magnet (CQM) connected in series with Collider Dipole Magnets (CDM's) and for a quench appearing in CQM. An active protection system is studied where all magnets except the CQM's have heaters. These heaters cause a spot quench in each of the CDM outer layer conductors. Results indicate that the scheme is safe for a total induced quench time delay of less than 230 ms.

I. INTRODUCTION

Preliminary simulations of the quench protection system for the SSC [1] considered only the Collider Dipole Magnets (CDM). These simulations were made with the program SSC-RR which calculates the longitudinal quench velocity for each conductor in the coil using the adiabatic quench velocity expression [2]

$$v_q = \frac{J_{co}\sqrt{L_o}}{\gamma(\delta C)_m}\frac{q}{\sqrt{1-q+\delta\theta/(\theta_c-\theta_o)}}\ , \tag{1}$$

where J_{co} is the magnetic field dependent critical current density at the bath temperature θ_o, $L_o = 2.45 \times 10^{-8}$ WΩK^{-2} is the Lorentz number, γ is the copper to superconductor (s.c.) ratio, θ_c is the critical temperature at zero current, q is ratio of the operation current density to the critical current density, $\delta\theta$ is a small shift in the generating temperature, $\theta_g = \theta_c - (\theta_c - \theta_o)q$, and $(\delta C)_m$ is the average of the product of the density δ times the specific heat C of the metal components in the conductor. The temperature θ for each conductor is estimated through the solution of the equation

$$(\delta c)\frac{d\theta}{dt} = \rho J^2\ , \tag{2}$$

where ρ is the total resistivity of the conductor, J is the current density flowing in the conductor, t is the time, and (δc) is the average of the product of the density times the specific heat of all the components of the conductor. The thermal conductivity of the conductor is ignored in equation (2) since the quench velocity is much higher than the thermal diffusion velocity. However, this thermal conductivity effect is considered when calculating the temperature profile along the conductor [3]. The heat is not transferred to the helium because it has a small effect on the quench characteristics. The transverse quench propagation is estimated using the experimental values (current dependence) from Reference 1. The voltage between the normal zone and the s.c. zone in the magnet is approximated by the following expression

$$V = R_Q I(1 - M/L) + MV_{cs}/L\ , \tag{3}$$

where R_Q is the total quench resistance in the coil (normal zone), I is the current, V_{cs} is the voltage across the magnet, L is the magnet self inductance, and M is the mutual inductance between the part of the coil formed by the normal zone and the other part of the coil which is still superconducting (s.c.).

The hot-spot temperature, the highest temperature reached in the coil during a quench (which normally is located where the quench first appears), is the most important parameter affecting magnet safety. The peak voltage between the normal zone and s.c. zone (approximately the peak quench resistive voltage) is the other parameter of importance when internal breakdown voltages are in consideration. The characteristics of the CQM and CDM can be found in Reference [4]. It is clear that the magnetic field in the conductor must be taken into consideration to calculate the quench velocity and resistance developed. In what follows, the analysis of a single CQM passively protected and one CQM with several CDM's connected in series and actively protected will be presented. In the active protection system, CDM's will have heaters but the CQM does not have a heater.

II. SINGLE CQM (SELF PROTECTED)

The model for the electric circuit can be seen in the Figure 1. The initial current is 6500 A. The inner coil quench appears in the last conductor from the midplane (by symmetry only a quarter of the coil is considered) after the copper wedge in conductor 8. The quench propagates all the way down across the wedge and upward across the insulator layer between the inner and outer coils. The first conductor quenching in the outer coil will be the closest one to inner conductor 8 which is conductor 13. In the outer coil case, the quench starts at conductor number thirteen, and propagates all the way down and into the inner coil, quenching conductor 8 first.

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Figures 2 and 3 show the temperature evolution of these conductors for the inner and outer coil quench, indicating the CQM is a self protected magnet (the hot-spot temperature is less than 170 K).

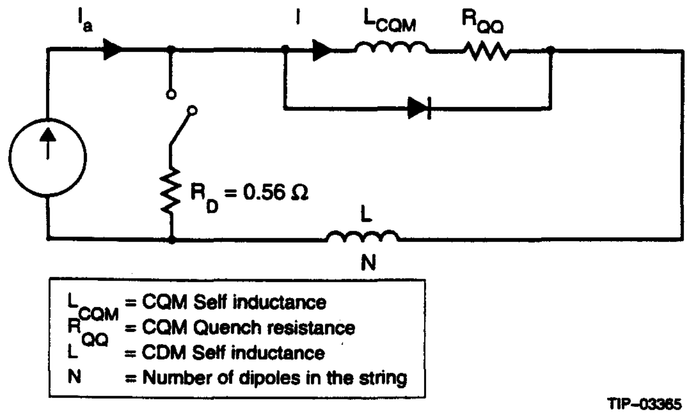

Figure 1. Passive Protection System Circuit Model.

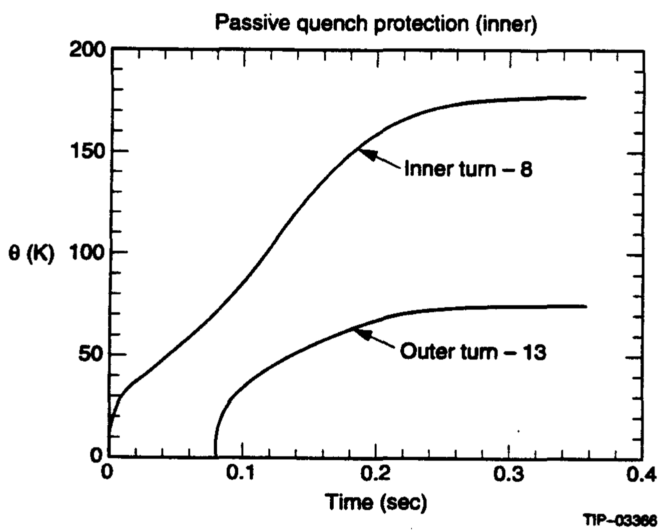

Figure 2. Quench Starts in the Inner Coil (turn 8).

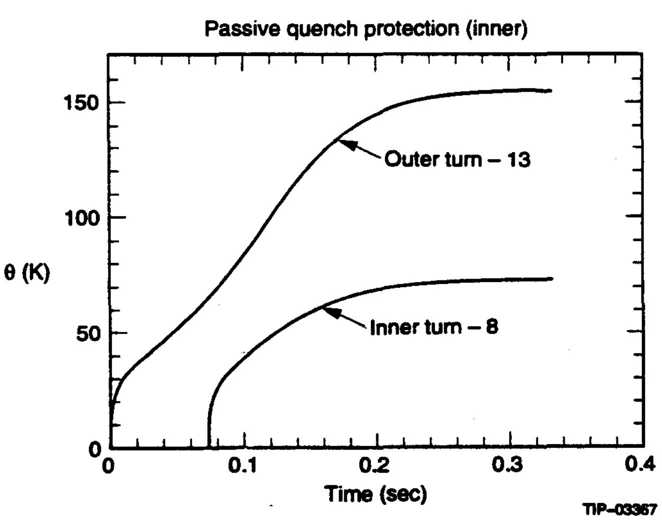

Figure 3. Quench Starts in the Outer Coil (turn 13).

III. ACTIVE PROTECTION SYSTEM FOR ONE CQM IN SERIES WITH CDM'S

The model for the electric circuit can be seen in Figure 4. The initial current here is also 6500 A. Since the difference in temperatures for the inner and outer coil quenches is not significant, the inner coil quench case will be the only one presented here. After the CQM quench initiates, the heaters induce a CDM quench at the time "bypass – time + τ_h" at a single point (worst case heater performance) on each conductor of the dipole outer coils. The quench velocity on these magnets and all the quench characteristics (temperature, peak voltage, resistance, *etc.*) are then calculated. Figure 5 summarizes the evolution of the temperature in the CQM for several dipoles connected in series with a quadrupole. Figure 6 shows that when the quadrupole is connected in series with dipoles, the longer current decay time results in a higher and more uniform temperature in the CQM bringing about higher total resistance. This fact is very important for a correct estimation of the quench behavior of the system. An underestimation of this resistance may result in the design of an unnecessarily complicated quench protection system. In the above calculations the heater time delay for the dipole magnets has been set to $\tau_h = 45$ ms. Figure 7 shows the number of miits developed in the quadrupole magnet for several CDM's connected in series and for three heater delay times. As can be see in this figure, even for a heater delay time of about $\tau_h = 150$ ms, the hot-spot temperature for the configuration D+D+Q will be about 400 K.

The case for a dipole quench in the system can be seen in the Reference 1. The presence of the quadrupole in this case is irrelevant since its stored energy is one order of magnitude lower, and most of the stored energy is dissipated in the dipoles (mainly in the one where the quench appeared first).

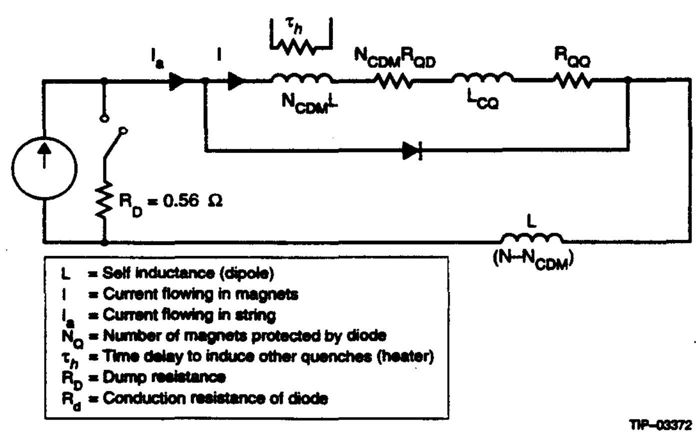

Figure 4. Circuit Model for the Active Protection System.

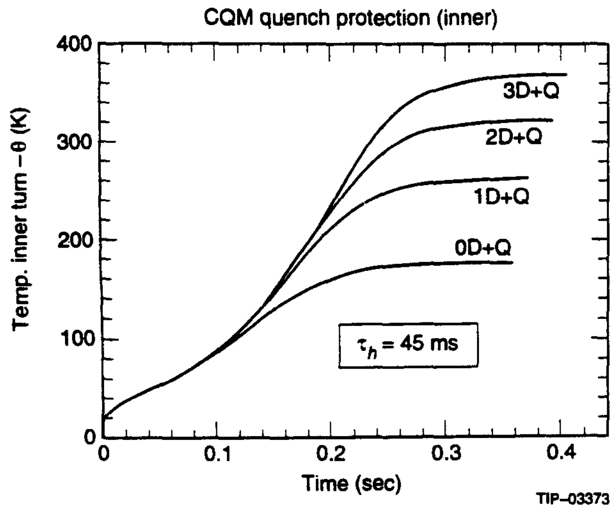

Figure 5. CQM Hot-Spot Temperature Evolution for various CDM's in Series.

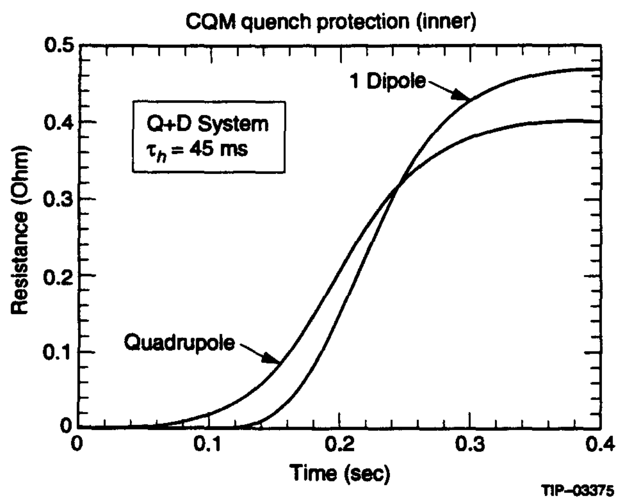

Figure 6. Total CQM Resistance Developed in the System CQM+CDM.

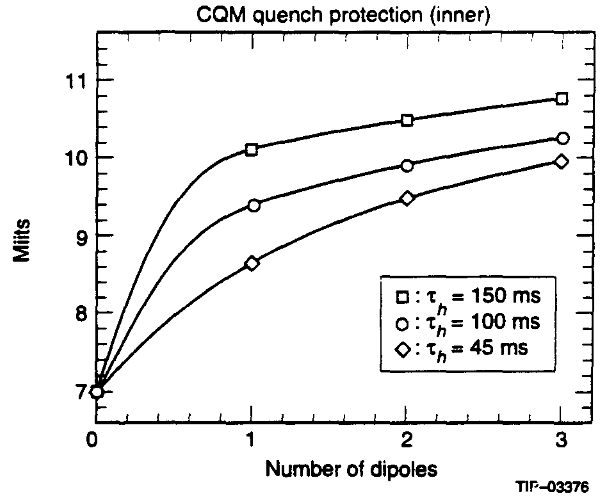

Figure 7. CQM Number of Miits Developed for several CDM's.

IV. SUMMARY AND COMMENTS

Passive protection system simulations agree with the experimental fact that the 40 mm aperture quadrupole magnet for the Collider is self protected. Active protection system simulations suggest that the scheme as shown here presented is a safe quench protection scheme. ASST experiments could test this option for the SSC. In the simulations it is assumed that the heaters cause a quench at a single point of each conductor of the outer CDM coil, then the quench propagates according to the longitudinal quench velocity, the time delay for transverse propagation, the magnetic field, *etc.* Actually, the heaters will be capable of quenching a large portion of the outer coil simultaneously. Hence, the assumption taken here should reflect the worst case scenario. Recall that the heater time delay τ_h in the simulation is in addition to the approximately 80 ms of delay from the start of the quench in the quadrupole. This is the time required for current in the system (D's+Q) to bypass the magnets and it is assumed in the simulations that at this time the quench is detected. Therefore, the total time delay safe limit, after the start of quench in the quadrupole, is about 80 ms + 150 ms = 230 ms. Finally, it is pointed out that these results will be also valid in case of changing the 40 mm CQM for a 50 mm CQM.

V. ACKNOWLEDGEMENTS

I wish to thank Dr. R.Meinke and Dr. R. Schwitters for their support at the SSC.

VI. REFERENCES

[1] G. López and G. Snitchler, SSCL-283, June 1990.

[2] G. López, SSCL-424, May 1991.

[3] G. López, SSCL-425, May 1991.

[4] SCDR, SSCL-SR-1056, July 1990.