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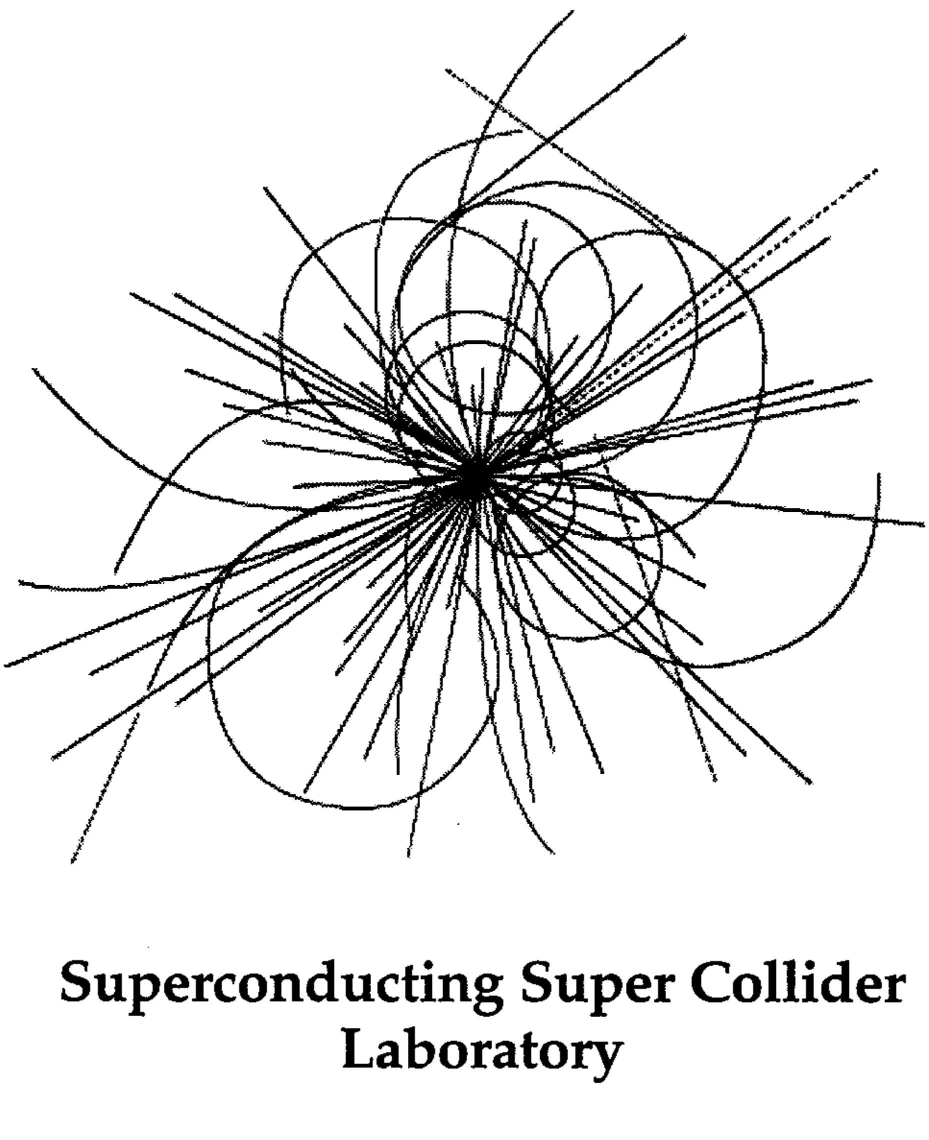

Superconducting Super Collider Laboratory

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Transient Response of the 20 K Shield of the Collider Dipole Magnet Cryostats*

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1. INTRODUCTION

The Collider maintenance operation involves replacement of a ring component such as a magnet or spool. For this operation, the cryogen flows through the section and strings including the faulty component are rerouted [1]. During emptying and warmup of these strings, the 20 K flow to remaining two strings on the other side of the refrigerator may have to be interrupted. Without active cooling, it is very important to understand the transient response of the 20 K shield, and to estimate the increased load on the coldmass (4 K system) as a result of the elevation in the 20 K shield temperatures.

2. ANALYSIS

A nominal Collider cryogenic string is 4320 m long, and is composed of a recursive structure of dipoles, quadrupoles and spool pieces, with dipoles accounting for most of the length. The heat load on the 20 K shield and the 4 K coldmass can be averaged over the length, and the problem may be analyzed by using the dipole parameters to arrive at geometric and physical parameters on a per unit length basis. As we will discuss later, dipole parameters alone are not sufficient to represent the discrete spikes in the heat loads, e.g. in the spool pieces. Such discrete loads can also be distributed over the length, by defining an average effective resistance.

Dipole parameters:

The following parameter values are used the analysis:

- Length = 15 m
- 80 K Shield circumference = 1.95 m
- 20 K Shield circumference = 1.80 m
- Cold mass perimeter = 1.3 m (including 0.2 m, half the perimeter of 4 K return lines)
- 20 K and 80 K shield surface emissivities = 0.05
- Cold mass surface emissivity = 0.04

- 20 K Shield thickness = 2 mm
- 20 K Shield mass per unit length = 9.72 kg/m (density of Al = 2700 kg/m^3)
- 20 K pipe inner diameter = 0.085 m (with 1.5 mm wall thickness)
- 20 K pipe mass/length = 3.163 kg/m (density of SS = 7900 kg/m^3)

- Number of support posts = 5
- Support post: General Dynamics straight post design with syntactic core sandwiched between carbon/epoxy plies [2]:
- Syntactic core cross-section = 537 mm^2
- Carbon/epoxy cross-section = 1166 mm^2
- Post length between 20 K and 80 K intercepts = 36.0 mm
- Post length between 4 K and 20 K intercepts = 25.8 mm

Initial conditions and heat loads:

- 80 K Shield temperature = 90 K
- 20 K Shield temperature = 20 K
- Cold mass temperature = 4 K

Based on radiant exchange between concentric cylinders, heat transfer by radiation from the 80 K shield to the 20K shield, and from the 20K shield to the 4 K cold mass are given by:

$$q'_{rad,20K-4K} = -q'_{rad,4K-20K} \equiv -A'_{4K} F_{4K-20K} \overline{\sigma}(T^4_{4K} - T^4_{20K})$$
$$q'_{rad,80K-20K} = -q'_{rad,20K-80K} \equiv -A'_{20K} F_{20K-80K} \overline{\sigma}(T^4_{20K} - T^4_{80K})$$

where $F_{a-b} = [\varepsilon_a^{-1} + A_a A_b^{-1}(\varepsilon_b^{-1} - 1)]^{-1}$ and the prime denotes quantity per unit length.

Heat transfer by conduction through the composite post is given by:

$$q'_{cond,20K-4K} = \left[(A_{ce} / L_{20K-4K}) \int_{T_{4K}}^{T_{20K}} k_{ce} dT + (A_{sc} / L_{20K-4K}) \int_{T_{4K}}^{T_{20K}} k_{sc} dT \right] (n_{post} / L_{dipole})$$
$$q'_{cond,80K-20K} = \left[(A_{ce} / L_{80K-20K}) \int_{T_{20K}}^{T_{80K}} k_{ce} dT + (A_{sc} / L_{80K-20K}) \int_{T_{20K}}^{T_{80K}} k_{sc} dT \right] (n_{post} / L_{dipole})$$

Using the above parameters and material properties, the initial (steady-state) heat loads per unit length can be calculated:

$$q'_{rad,20K-4K} = 0.0003 \text{ W/m}$$
$$q'_{cond,20K-4K} = 0.0060 \text{ W/m}$$
$$q'_{rad,80K-20K} = 0.180 \text{ W/m}$$
$$q'_{cond,80K-20K} = 0.176 \text{ W/m}$$

Hence, based on dipole contributions, the 4 K and 20 K heat loads are 0.0063 W/m and 0.3497 W/m, respectively. These loads are lower than the corresponding string static design loads, which are 0.07 W/m for the 4 K line and 0.5 W/m for the 20 K line. The disagreement between the calculated and the nominal loads is particularly large for the 4 K line. Only one-fourth of the nominal 4 K load is allocated to the dipoles; majority of the 4 K static load is through the spools. Therefore, dipole parameters alone cannot be used to characterize and estimate the 4 K heat load. This is also true for the 20 K load. Gas conduction is neglected in this discussion. In order to compensate for the discrepancy between the calculated loads and nominal loads, we assume that the difference can be attributed to an effective resistance representing the conductive contributions through the rest of the string elements. Thermal conductivity of stainless steel is used to characterize this resistance:

$$(A / L)'_{ss,20K-4K} = \left[q'_{nom,4K} - (q'_{rad,20K-4K} + q'_{cond,20K-4K})\Big|_{time=0} \right] / \int_{T_{4K}}^{T_{20K}} k_{ss} dT$$
$$(A / L)'_{ss,80K-20K} = \left[q'_{nom,20K} + q'_{nom,4K} - (q'_{rad,80K-20K} + q'_{cond,80K-20K})\Big|_{time=0} \right] / \int_{T_{20K}}^{T_{80K}} k_{ss} dT$$

TRANSIENT RESPONSE

There are three heat transfer paths used to calculate the energy balance and estimate the transient response for the 20 K shield are: radiation between surfaces; conduction through the post; and conduction through an effective stainless steel resistance (see Figure 1). Gas conduction is omitted. Assuming that the 80 K shield and cold mass continue to be cooled at the initial levels, i.e. maintained at 90 K and 4 K respectively, the change in the combined energy of the 20 K shield and pipe is given by:

$$(w'_{shield}c_{p,Al} + w'_{pipe}c_{p,ss})\frac{dT_{20K}}{dt} = (q'_{rad,80K-20K} + q'_{cond,80K-20K} + q'_{ss,80K-20K}) - (q'_{rad,20K-4K} + q'_{cond,20K-4K} + q'_{ss,20K-4K})$$

where $(q'_{rad,20K-4K} + q'_{cond,20K-4K} + q'_{ss,20K-4K})$ is the instantaneous load on 4 K coldmass.

The above equation is integrated using the RKF45 ODE integrator [3]. The solution for the 20 K shield temperature and the resulting heat load on the 4 K system are shown in Figures 2 and 3 respectively. The 20 K shield temperature rises rapidly when the 20 K shield flow is stopped: it increases from 20 K to 30 K within 2 hours, and to 40 K in 10 hours. The new equilibrium temperature is 45 K and the corresponding 4 K heat load is 0.481 W/m or 2075 W per string. The heat load on the 4 K coldmass also increases rapidly, doubling within 1 hour and quadrupling in 4.5 hours.

In the above energy balance, the thermal capacity of the helium in the 20 K pipe is neglected. This is a somewhat conservative assumption: the overall change (from 20 K to 45 K) in the enthalpy of helium in the 20 K line is small compared to that of the shield metal (< 10%), but comparable at the lower temperatures in the beginning of the process. Therefore, the above results slightly overpredict the rate of increase in the 20 K shield temperature at the initial stages.

REFERENCES

1. R. Than, S. Abramovich, and V. Ganni, "The SSC Cryogenic System Design and Operating Modes," *SSC Cryo Note 92-12*, SSC Laboratory, Dallas, Texas, October 1992.

2. General Dynamics, "15 M CDM Predicted Cryostat Heat Leak Based on Thermal Conductivity Test Data," Technical Data Transmittal #890-92-P-1133, San Diego, California, May 20, 1993.

3. G. Forsythe, M. Malcolm, and C. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, New York, 1977.

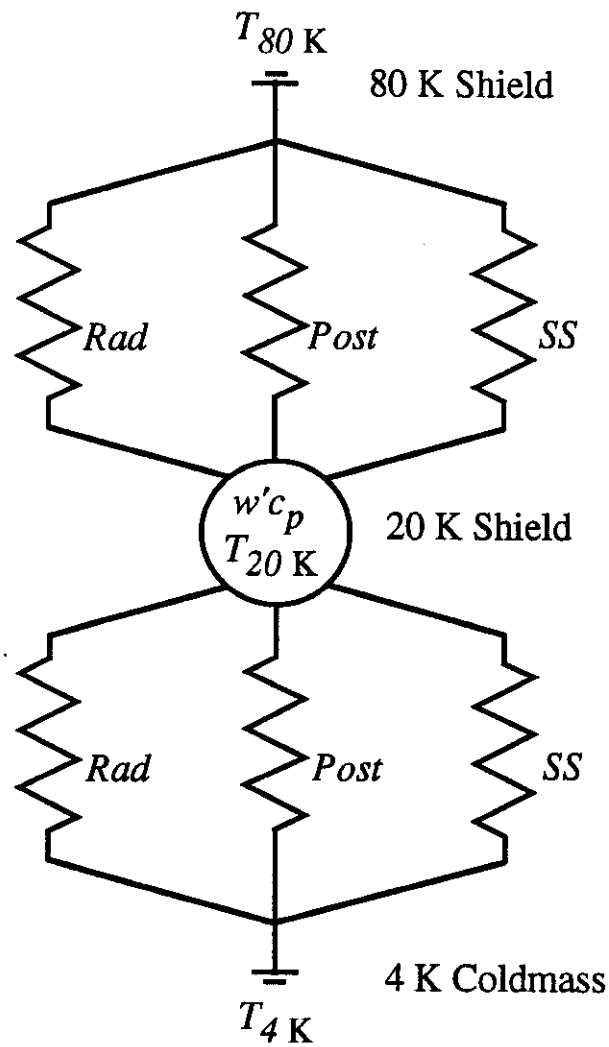

Figure 1. Energy balance for the 20 K Shield

20 K Shield Temperature

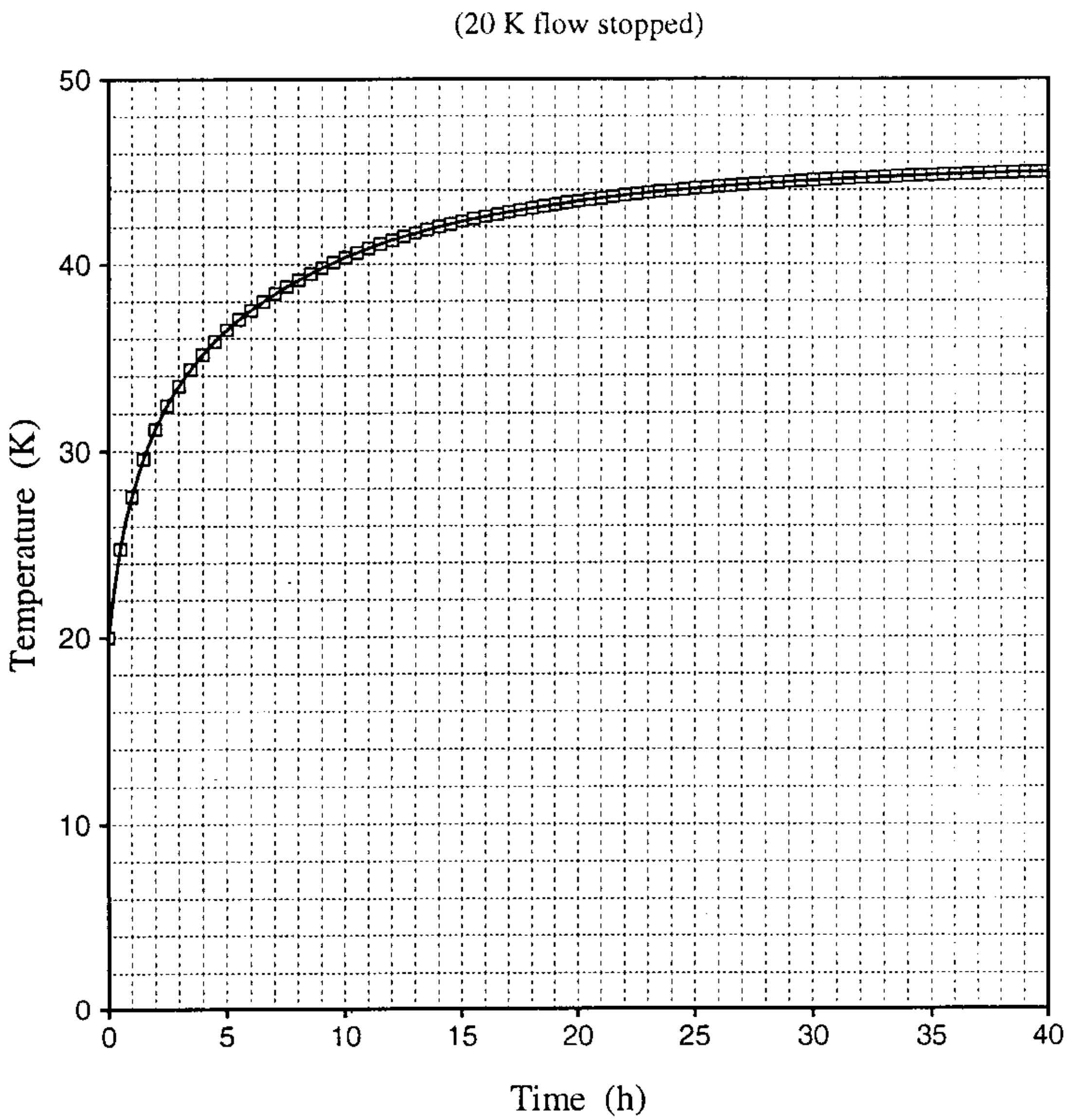

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Figure 2

4 K Heat Load (W/m)

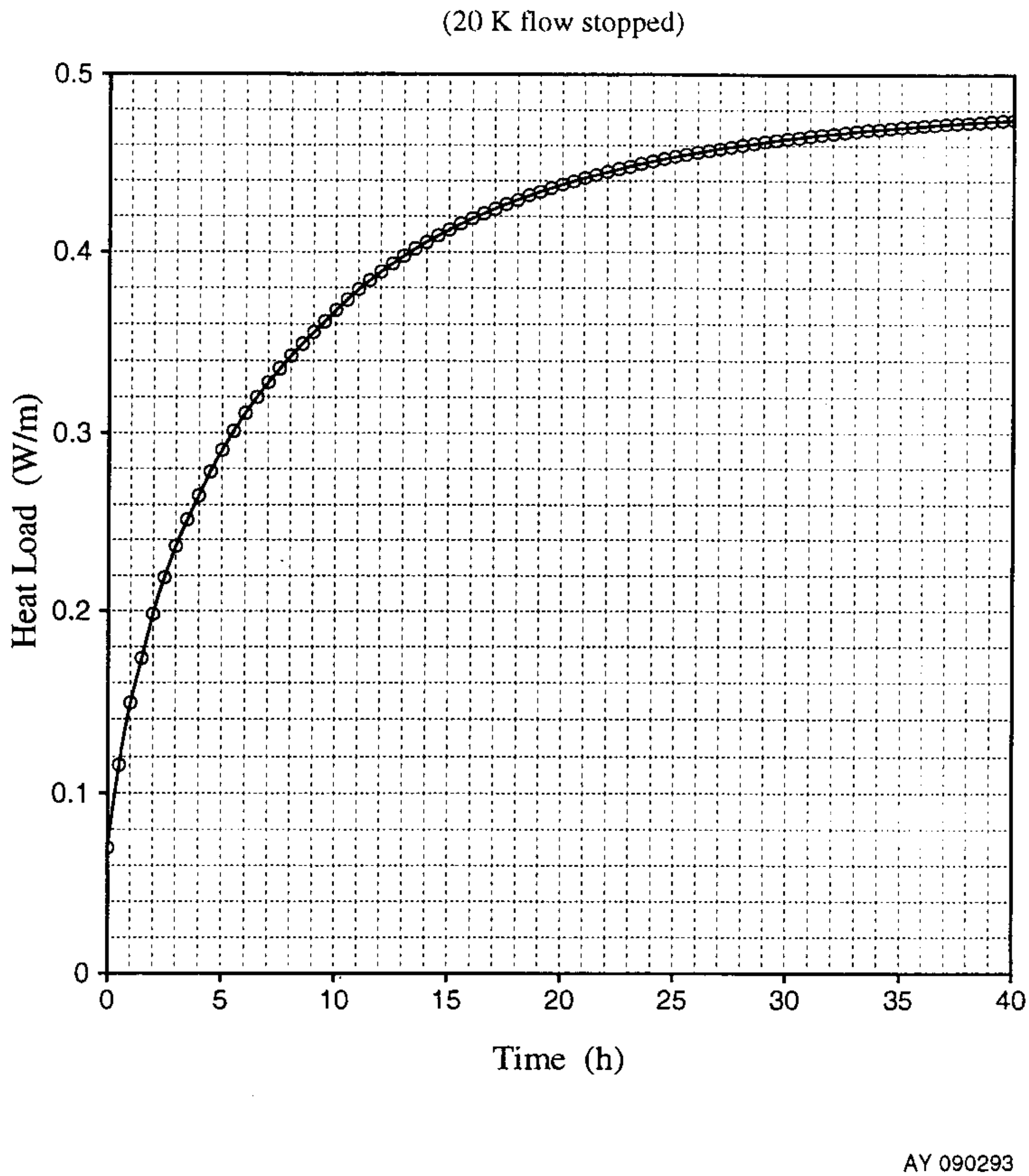

Figure 3