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A Proposed IR Quad for the SSC

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ABSTRACT

This note outlines a detailed magnetic design of a high-gradient quadrupole for the beam interaction region of the SSC. The 58 mm bore, 2 layer magnet uses 36 strand cable identical to the collider dipole magnet outer cable, thin collars, a close-fitting iron yoke, and a shell for structural support. With a 1.3:1 Cu/Sc ratio the quadrupole short sample gradient is 274 T/m at 1.9 K and 209.7 T/m at 4.35 K with good field quality. Assembled with 7 mm collars, the magnet is placed inside a four-segment iron yoke and prestressed with welded outer shell. Prestress is maintained during cooldown by aluminum spacers placed between the segmented iron yoke blocks. This paper describes various conceptual design details including coil geometry, load line and margin, field uniformity and saturation effects.

INTRODUCTION

Two low beta quadrupole triplets are to be installed at the SSC interaction region. The quadrupole closest to the interaction region (QL 1) is required to have a high gradient, excellent field uniformity, and sufficient cooling to withstand beams with 10^{33} luminosity. For good field uniformity, the bore diameter is compared to the current 40 mm collider quadrupole bore diameter. Increasing the bore size to 58 mm has a direct effect on improving the field uniformity as compared to the 40 mm bore quadrupole but will decrease the gradient. In order to maximize the gradient, Jc is increased by cooling the magnet to 1.9 K and reducing the copper to superconductor ratio. In addition, the contribution of the iron is maximized by minimizingthe collar size. In this paper we outline a magnetic design and propose a construction and assembly procedure based on a thin collar.

THE MAGNET

The main features of the magnet include a double layer "Cosine 2θ" winding, a set of four-way collars and iron yoke, four aluminum spacers and a shell (Figure 1). The cable used in both layers is the same size as the 36 strand cable used in the outer layer of the collider dipole (Figure 2). The NbTi strand diameter is 0.648 mm (0.0255") with a Cu/Sc ratio of 1.8:1, we consider however, the possibility of using 1.3:1 strand. The coil has a single wedge in each layer with 13 turns and 20 turns in the inner and outer coils respectively (Figure 3). The outer layer pole turn is intentionally left one conductor thickness away from the inner layer pole; this simplifies the transition between layers during winding (in the end region the outer layer gains a turn around the pole and the inner layer loses one). Special cooling channels were introduced between layers and along the pole. These channels are thermally linked to the refrigerant located inside 16 circular holes in the yoke introduced specifically to remove heat.

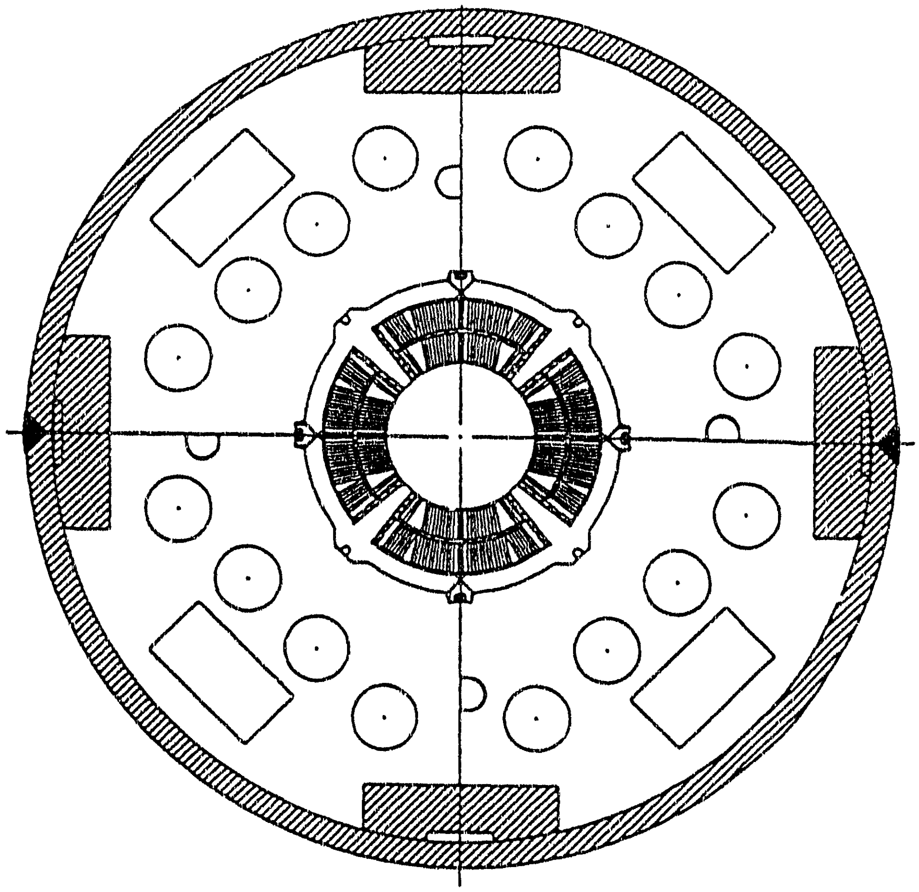

Figure 1 Low beta quad cross-section

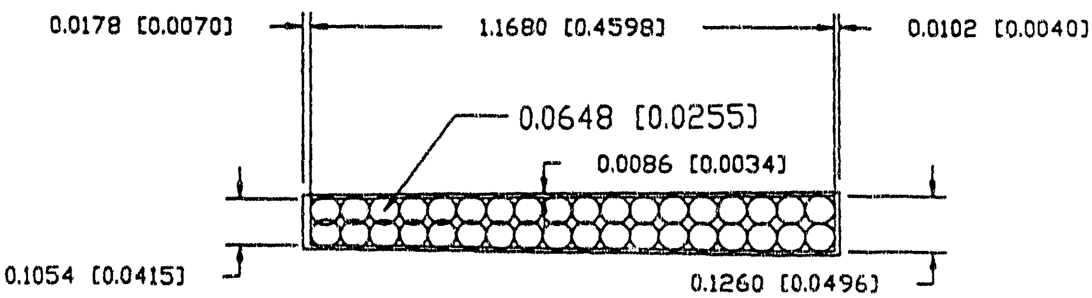

Figure 2 a 36 strand cable used in layers 1 and 2

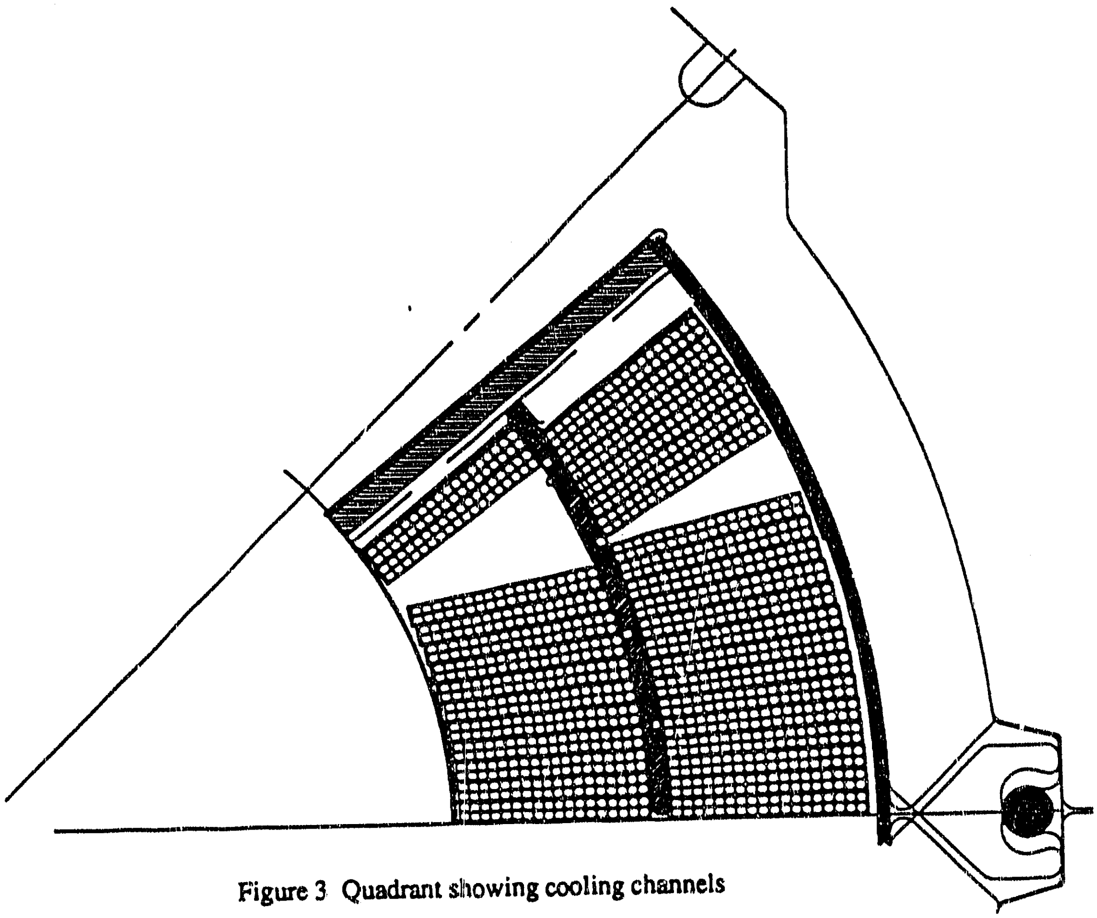

Figure 3 Quadrant showing cooling channels

COIL-COLLAR-YOKE AND SHELL ASSEMBLY

The use of thin collars and aluminum spacers to control the yoke gap assembly is a unique feature of the design that has previously been successfully tested in a dipole magnet (magnet D19 — to be published). The entire coil prestress comes directly from the outer shell and both prestress level and cooldown loss are controlled by the four aluminum spacers. The collars provide precision conductor location andminimum prestress as an assembly aide. A 7 mm thick stainless steel collar is sufficient to hold the coils at assembly with a prestress of 1500 psi. The key and keyway are designed to unload during cooldown. The collared coil is placed inside an iron yoke which is split four ways. Special tabs are introduced along the 45 degree poles of the collar and yoke to aid in alignment. Four aluminum spacers are placed in slots along the yoke and a stainless steel shell is then pressed around the assembly and welded. The shell is an integral part of the magnet helium container as in the collider dipoles and quadrupoles. As the shell exerts force on the assembly the coil reaches its predetermined prestress, and a small well controlled gap (about 5 mils) is maintained by the aluminum spacers along the midplane between the four-way yoke. As the magnet cools and reduces in size so do the aluminum bars; the gap closes, and the coil prestress is maintained approximately constant.

MAGNETIC DESIGN

The coil was designed to give negligible multipoles. Theoretically the systematic b_5,b_9, and b_{13} are 4.5×10^{-4}, -1.7×10^{-2}, and -1.7×10^{-4} units respectively (one unit is 10^{-4} of the quadrupole field at r=10 mm). The introduction of iron saturation causes b_5 to vary by 0.14 units and b_9 to vary by less than 0.004 units (Figure 4). The initial transfer function of 3.03 (G/cm/A) is reduced with excitation by 7.6% at 10000 A (Figure 5). A flux plot at I=11000 A is shown in Figure 6.

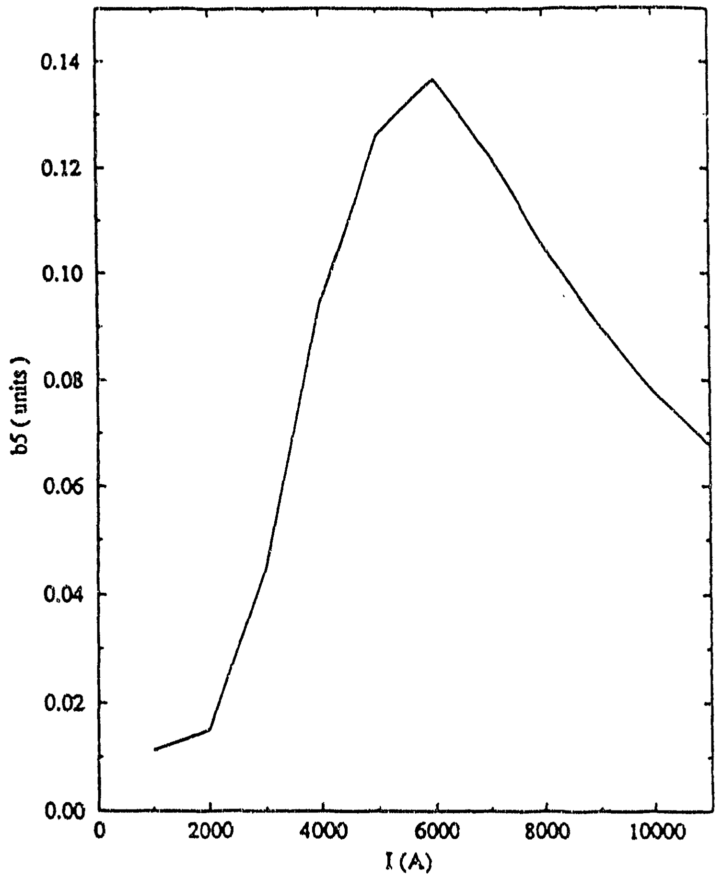

Figure 4
The effect of iron saturation on b5

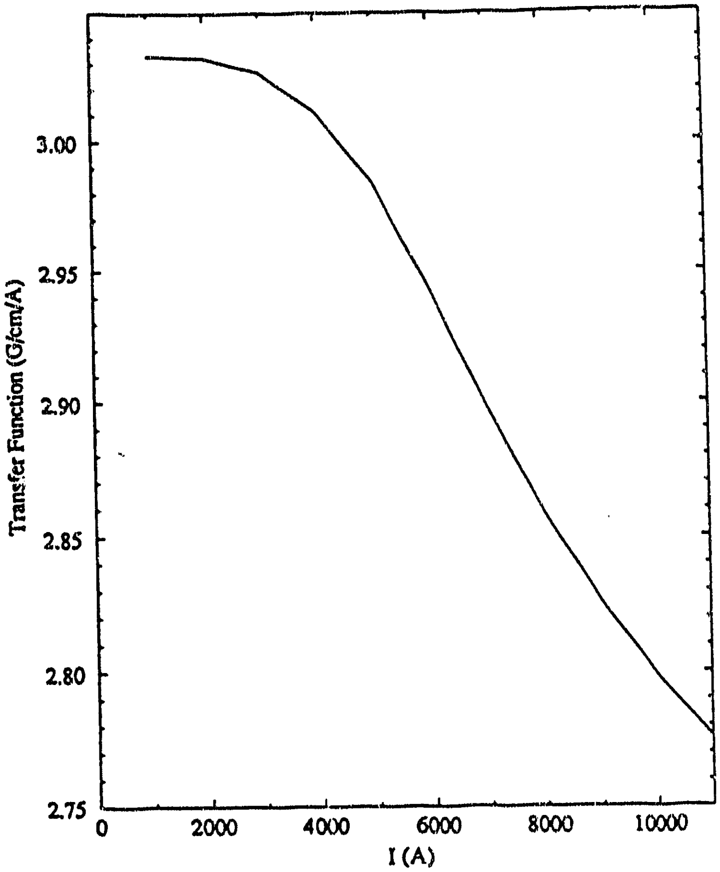

Figure 4
The effect of iron saturation on the transfer function.

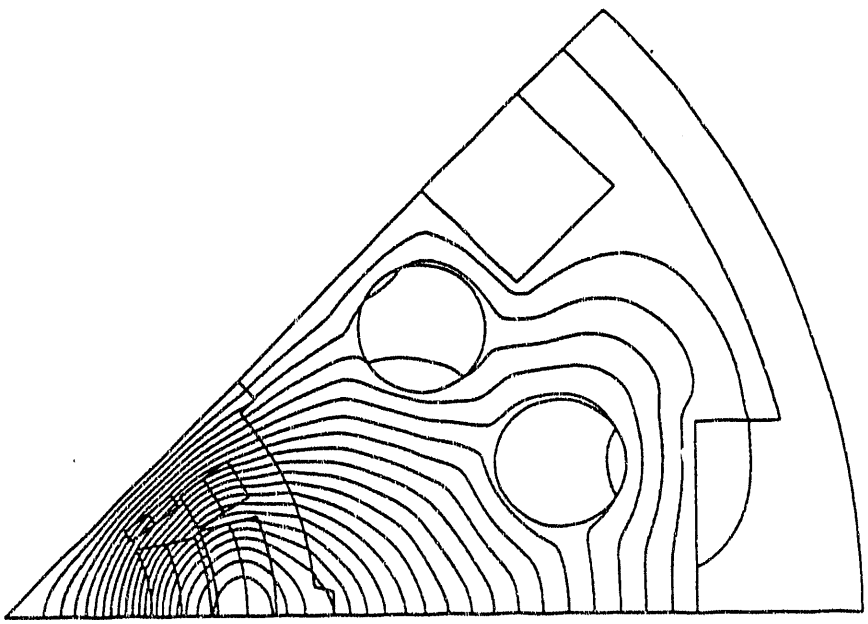

Figure 6
Flux plot at 11000. A.

The load line and short sample performance are included in Figures 7 and 8 for the inner layer. Results for the outer layer are not included here as it has a higher margin. The short sample curves were computed at 4.35 K and 1.9 K assuming J_c=2750 (A/mm²) at 4.2 K and 5 tesla [1]. Table 1 summarizes the short sample performance and Table 2 assumes a set of values for a 15% margin. With a variation in temperature and Cu/sc ratio an operating gradient between 169 (T/m) and 232 (T/m) can be expected with a margin of 15%. The stored energy at 5755 A and 7709 A is 66 (kJ/m) and 112 (kJ/m); the respective inductance is 3.95 (mH/meter) and 3.78 (mH/meter).

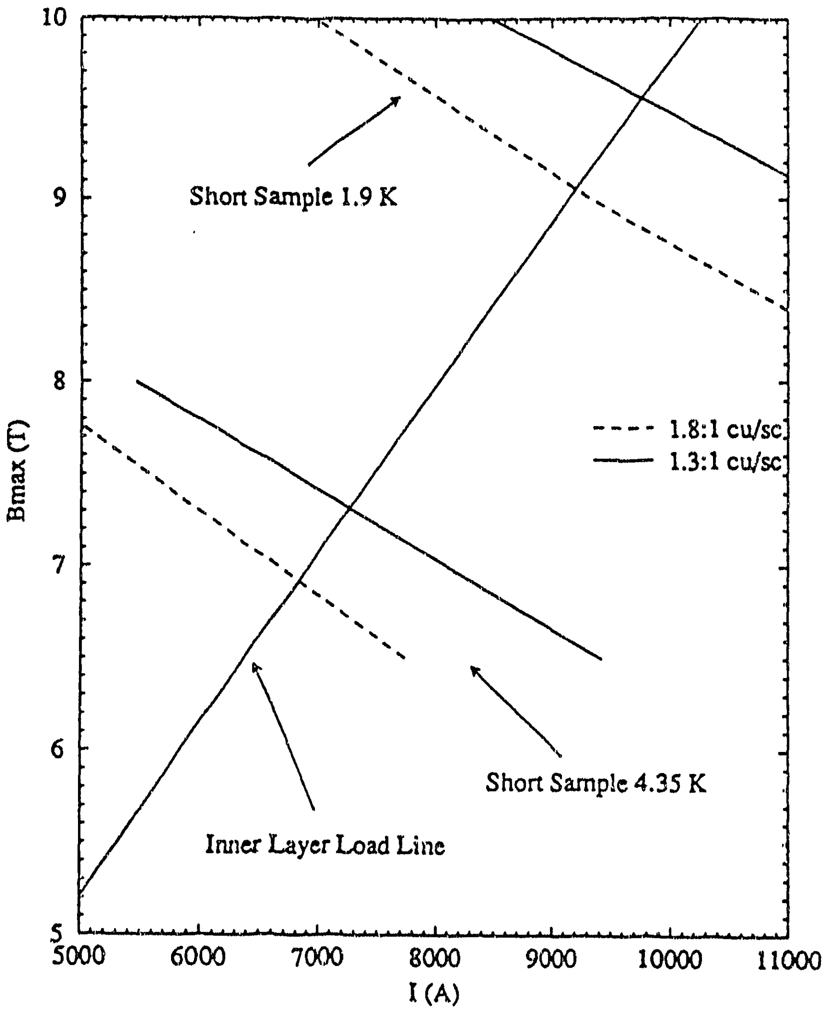

Figure 7 Short sample and load line

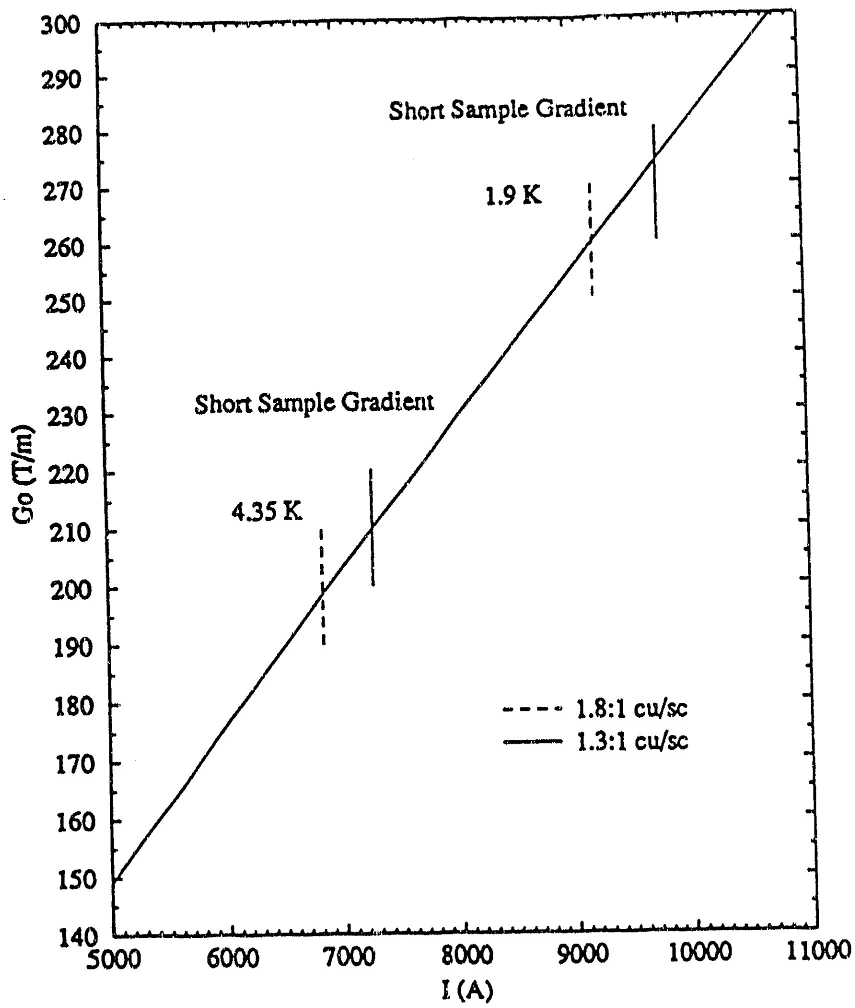

Figure 8 The gradient as a function of current

Table 1 Short sample values for the IR quad

Operating Temperature	Cu/Sc 1.8:1 NbTi			Cu/Sc 1.3:1 NbTi		
To (K)	*Iss (A)*	*Bss (T)*	*Goss (T/m)*	*Iss (A)*	*Bss (T)*	*Goss (T/m)*
4.35	6835	6.915	198.4	7273	7.31	209.7
1.9	9208	9.05	259.5	9770	9.55	274

Table 2 Operating point with 15% margin

Operating Temperature	Cu/Sc 1.8:1 NbTi		Cu/Sc 1.3:1 NbTi	
To (K)	*Io (A)*	*Go (T/m)*	*Io (A)*	*Go (T/m)*
4.35	5755	169	6098	178
1.9	7709	221	8182	232

He II HEAT TRANSFER

Heat transfer to He II along the magnet was calculated for two cases, one where the entire heat is applied at one end, and the other where the heat is uniformly distributed along the magnet. The mechanism of heat transfer is based on the Gorter-Mellink two fluid model, and simple relations were used here based on Reference[2]:

End Heating

$$q = 8.593 \left(\frac{\Delta T}{l}\right)^{0.294}$$

q=(w/cm^2) ; T=K ; l=cm

Uniform Heating

$$q = 13.286 \left(\frac{\Delta T}{l}\right)^{0.294}$$

Sixteen holes of 1.27 cm radius in the iron yoke and the 2 unused bus holes will remove over 50 watts of uniform heating via axial heat conduction over a 16 m length with negligible ΔT along the length.

REFERENCES

[1] M.A. Green. Generation of the Jc, Hc, Tc surface for commercial superconductor using reduced-state parameters. *Lawrence Berkeley Laboratory LBL-24875, UC-406*, April 1988.

[2] S. Caspi. Phenomenological relations concerning heat transfer to He II. *Lawrence Berkeley Laboratory LBID-726, SU-MAG-95*, May 1983.

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