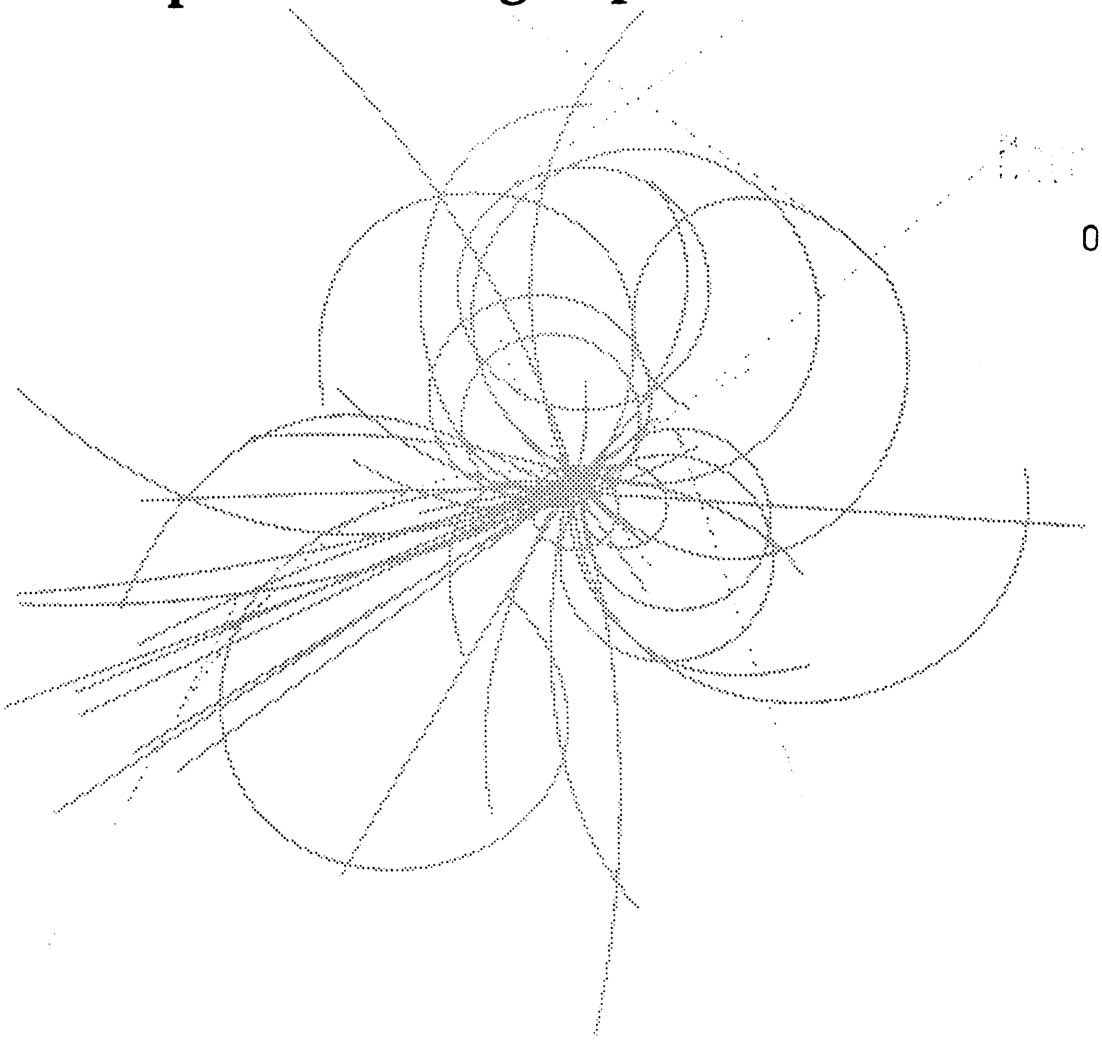
ConF- 900944--53

SSCL-404

SSCL-404

Superconducting Super Collider Laboratory

OCT 2 3 1991



SSC 40 mm Cable Results and 50 mm Design Discussions

D. Christopherson, D. Capone, R. Hannaford, R. Remsbottom, R. Delashmit, R. Jayakumar, and G. Snitchler, et al

September 1990

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SSCL--404

DE92 001660

SSC 40 mm Cable Results and 50 mm Design Discussions[*]

D. Christopherson, D. Capone, R. Hannaford, R. Remsbottom,
R. Jayakumar, and G. Snitchler

Magnet Division
Superconducting Super Collider Laboratory[†]
2550 Beckleymeade Ave.
Dallas, TX 75237

and

R. Scanlan and J. Royet

Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

September 1990

---

[*] Submitted to the Applied Superconductivity Conference, Snowmass, Colorado, September 24–28, 1990.

[†] Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC02-89ER40486.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SSC 40 mm CABLE RESULTS AND 50 mm DESIGN DISCUSSIONS

D. Christopherson, D. Capone, R. Hannaford, R. Remsbottom, R. Delashmit
R.J. Jayakumar, G. Snitchler
Superconducting Super Collider Laboratory
2550 Beckleymeade Ave.
Dallas, TX 75237

R. Scanlan, J. Royet
Lawrence Berkeley Laboratory
1 Cyclotron Rd.
Berkeley, CA 94720

Abstract

A summary of the cable produced for the 1990 40 mm Dipole Program is presented. The cable design parameters for the 50 mm Dipole Program are discussed, as well as portions of the SSC specification draft. Considerations leading to the final cable configuration and the results of preliminary trials are included. The first iteration of a strand mapping program to automate cable strand maps is introduced.

Introduction

Early in 1990 the decision was made to change the aperture of the SSC Dipole Magnet from 40 mm to 50 mm. A significant improvement in field quality, at a 10 mm radius, results from the increasing of the original 40 mm bore cross-section. In addition, the magnet was made much less sensitive to RMS variations associated with conductor placement, because the individual conductor elements are now further from the 10 mm reference radius than in the 40 mm design. Fortunately, as a result of the aperture increase, additional operating margin along the load line, was incorporated into the design. With this shift in magnet design, we were faced with the task of developing an optimum cable design which had the least possible schedule impact on the program. This work went on in parallel with our cabling obligations to the 40 mm Dipole Program.

40 mm Cabling Summary

Table 1 shows the summary of the 40 mm Dipole cable manufactured during 1990. This cable was fabricated to support the ongoing magnet performance investigations in the 40 mm plan, and does not include cable made for conductor research and development purposes. The cables listed in Table 1 were manufactured to meet specification SSC-MAG-M-4142, revision 3, and represent material from three different superconducting wire manufacturers.

Table 1. 1990 SSC Pre-Production Cable (40mm).
Made to specification #SSC-MAG-M-4142; minimum Ic values:
Outer = 7860A, 1.3:1 Inner = 7860A, 1.5:1 Inner = 7231 A

Cable #	Type	Length (m)	Ic 5.6T [7T]
SSC-O-I-00002	Outer	3434	8975
SSC-O-O-00013	Outer	676	8479
SSC-O-O-00014	Outer	686	8479
SSC-O-S-00015	Outer	1373	8075
SSC-2-I-00023	Outer	700	not available
SSC-2-I-00024	Outer	701	not available
SSC-I-S-00008	1.3 Inner	24[illegible]	[8094]
SSC-I-S-00009	1.3 Inner	272[illegible]	[8099]
SSC-I-S-00010	1.3 Inner	[illegible]2	[8368]
SSC-I-0-00011	1.3 Inner	980	[8603]
SSC-I-O-00016	1.3 Inner	1087	[8638]
SSC-I-I-00003	1.5 Inner	987	[7791]
SSC-I-I-00004	1.5 Inner	595	[7791]
SSC-I-I-00005	1.5 Inner	1290	[7791]

Cabling Machine Difficulties

Problems associated with the prototype cabling machine were encountered during the manufacturing of these cables, and certain modifications were made in order to produce high quality cable. Damage to the cable was determined to be a result of problems with the powered Turk's-head.[1] In one run, copper slivers seen between the strands in the cable were found to be caused by a slight difference in the diameters of the power driven top and bottom rollers of the Turk's-head. Disconnecting the driveshaft on the top roller allowed it to travel at the same speed as the bottom roller, eliminating the sliver problem.

During another run, it was discovered that the side rollers, which are not powered, were travelling at different rates causing filament breakage at the major edge of the cable. Misalignment of the major edge side roller put its point of contact too close to the center of the top (powered) roller. Because this side roller was driven by a smaller diameter on the top roller, it travelled slower and stretched the strands as they were pulled across its surface. To alleviate this problem, the surface of the side rollers were narrower to reduce the possible contact area, and realigned in the Turk's-head.

Derivation of 50 mm Cable Configuration

Major changes in the strand design were discounted by the SSC 50 mm Dipole Task Force because of the complications and schedule setbacks unavoidable during a re-optimization period. Even a slight change in strand diameter could involve a lengthy study and redesign effort. The critical current of the wire is determined by the heat treatments and subsequent cold drawing of the material throughout the process. Final strand size and extruded rod diameter determine the available strain space in which to fit the desired number of heat treatments. Heat treatment time and temperature also depend, in part, upon the available strain space in which to work. If this strain space is varied, strand optimization could involve variations of heat treatment time, temperature, number, and placement within the process. A strand diameter change would also affect the procedure as far back as the monofilamentary stage. If the filament diameter remains at 6 microns, and the multifilament billet size is fixed, then the hex size of the monofilament at restack and the number of filaments in the billet will change.

Even if the technical problems associated with such a redesign effort are ignored, the schedule delays due to lead times make major strand changes undesirable. Presently, lead times for conductor delivery are around 10 months. This would mean that no wire for 50 mm magnets would be available until 10 months after a contract has been awarded. This does not include specification revisions, cabling trials, winding trials, etc.

These arguments against significant changes in the superconducting strand left the focus on the cable configuration. Issues of coil prestress and distribution of stresses across the cable width suggested that the coil cross-section be approximately scaled in area from the 40 mm design to the 50 mm design. This would maintain the stress distribution across the cable face preventing any unfamiliar stress distributions across the cable. This was felt to be a conservative approach which would avoid any increased training in the 50 mm design from that obtained in the 40 mm design. A by-product of this decision was an improved margin between the maximum operating current and the Ic, which resulted from the additional conductor in the cross-section. This topic is more fully discussed elsewhere.[2]

The wider cable led to some concern about winding problems and other potential difficulties with such cable. However, it was reported to the task force that magnets have in the past, been built successfully using wide cable. During 1989, Lawrence Berkeley Laboratory built a 9T test magnet using wide cable made from SSC wire. This cable was simply a scale-up version of SSC 40 mm cable using a 28 strand Inner and a 36 strand Outer. In addition, the Europeans (Ensaldo built and Cern tested) had successfully produced magnets with cable of similar dimensions to what was being considered.

Inner Cable

A direct scale-up from the 40 mm design resulted in evaluation of a 28 strand Inner cable design. However, concerns over conductor stability facilitated a re-thinking of the copper to superconductor ratio needed. It was felt that a 1.3:1 Cu/SC ratio for Inner conductor was insufficient for quench stability, and that higher copper ratios be considered. Because SSC Inner with a 1.5:1 Cu/SC has been made successfully in the past, this choice became advantageous in terms of manufacturability. However, in order for a 1.5:1 cable to reach the desired quench field of 7.26T without reducing the operating temperature, 30 strands are needed instead of 28.[3] Calculations by G. Morgan show that 1.5:1 Cu/SC Inner would give the desired 10% field margin in a 30 strand cable,[4] and the additional copper would aid in quench stability. The Task force chose to conservatively recommend a 30 strand Inner cable with 1.5:1 conductor. Cabling and winding trials were used to fine tune the parameters.

Outer Cable

36 strand Outer cable was initiated by direct scaling to a 50 mm bore. Initially the task force discussed the possibility of increasing the Cu/SC ratio in the Outer conductor to 2.0:1 or higher. This would best match the Inner coil margin and have a small cost savings by reducing the amount of NbTi alloy used. These ideas were subsequently rejected as it was determined to be a significant task and not worth the small technical and economical advantages. An interest in keeping this conductor equivalent to the SSC quadrupole strand was also expressed in discussions. Therefore, 36 strand, 1.8:1 Outer cable was recommended by the task force to meet the 50 mm dipole requirements.

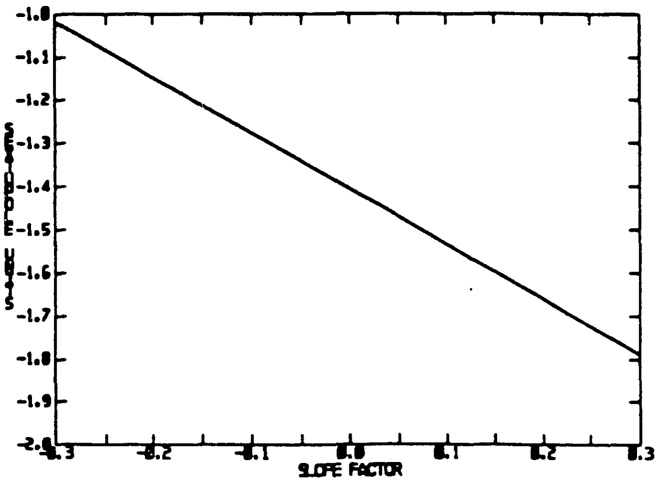


Figure 1. Variation of the sextupole unit with slope factor.

50 mm Cable Magnetization

The effect of varying field dependence of critical current density (Jc) for different cable production batches on the low field magnetization induced sextupole component in the dipole magnet has been calculated. The model is based on using an empirical formula[5] for the critical current which is derived from cable measurements. Since the specification of the cable will control the critical current at one specific field, the cable to cable variation is modelled by a factor which changes the slope of Jc vs B in the formula. The Jc, B, T dependence is then given as

$$Jc = P1(1 + (p_2\,u + p_3\,u^2 + p_4\,u^3)/(1 + p_5\,v))$$
$$((1 + p_6\,v)/(1 + p_7 v + p_8 v^2)\,F$$

where $F = (1 + (1 - B/6)*\text{slope factor})$, $u = T - 4.22K$,
$v = B - 5T$

The sextupole moment is modelled as being only due to an "effective" bulk magnetization and surface magnetization is not taken into account for this study on relative sextupole values. The bulk magnetization is calculated using the expression

$$M = (2/3p)*(m_0*Jc*d)*(1-(J/Jc))$$

where d is the filament diameter, J is the operating current density. The local magnetization is calculated for the local conductor field by segmenting the coil into 3000 elements and integrating over filaments per segment. The orientation of the local field in the conductor is taken into account in obtaining the orientation of current dipole. The sextupole value is obtained using standard[6] expressions for the actual persistent current and its image for the SSC dipole yoke iron (modelled with infinite permeability).

The variation of the sextupole unit with slope factor is shown in Figure 1. It is evident from the curve that the effect is quite linear with the near-zero field Jc. As the SSC specification for the RMS value of the sextupole is 0.8 units, it may be concluded that that a variation of 15% in low field Jc due to cable differences is acceptable.

Cabling and Coil Winding Trials

A series of trials were performed in order to optimize the resulting cable in terms of electrical and mechanical characteristics. R. Scanlan and J. Royet[7] cover such cable optimization for a generic set of Rutherford type cables. Early winding experiments with the 30 strand Inner cable suggested that a tighter lay pitch (see Fig. 2) be used to increase the flexibility of the cable in the "hard bend" direction. As a result of reducing the lay pitch from 92 mm to 86 mm, the width was forced to increase from 12.19 to 12.34 mm. These changes improved the ease of winding Inner coils.

The 36 strand Outer cable experienced a slightly different problem in its initial fabrication. The surface quality of the cable was not as uniform as it should be. The strands did not lay flat in the cable faces (referred to as "pop-outs"), leaving a "spongy" cable. Such cable can be prone to collapse (loss of cable form) or possible training when used in a magnet. To alleviate this problem, the compaction was increased. Thus, the midthickness dimension was decreased from 1.166 mm to 1.156 mm. Subsequent electrical tests performed at BNL on these trial cables have shown that this increased compaction still gives acceptable degradation figures, around 3.8%.

50 mm Cable Specification

Figure 2 shows a schematic of the 50 mm cables which is included in Specification Drafts SSC-MAG-M-4147 (Inner) and SSC-MAG-M-4148 (Outer). The changes in the cable specifications from the 40 mm design to the 50 mm design all relate to the increased number of strands in the cable; 36 strands

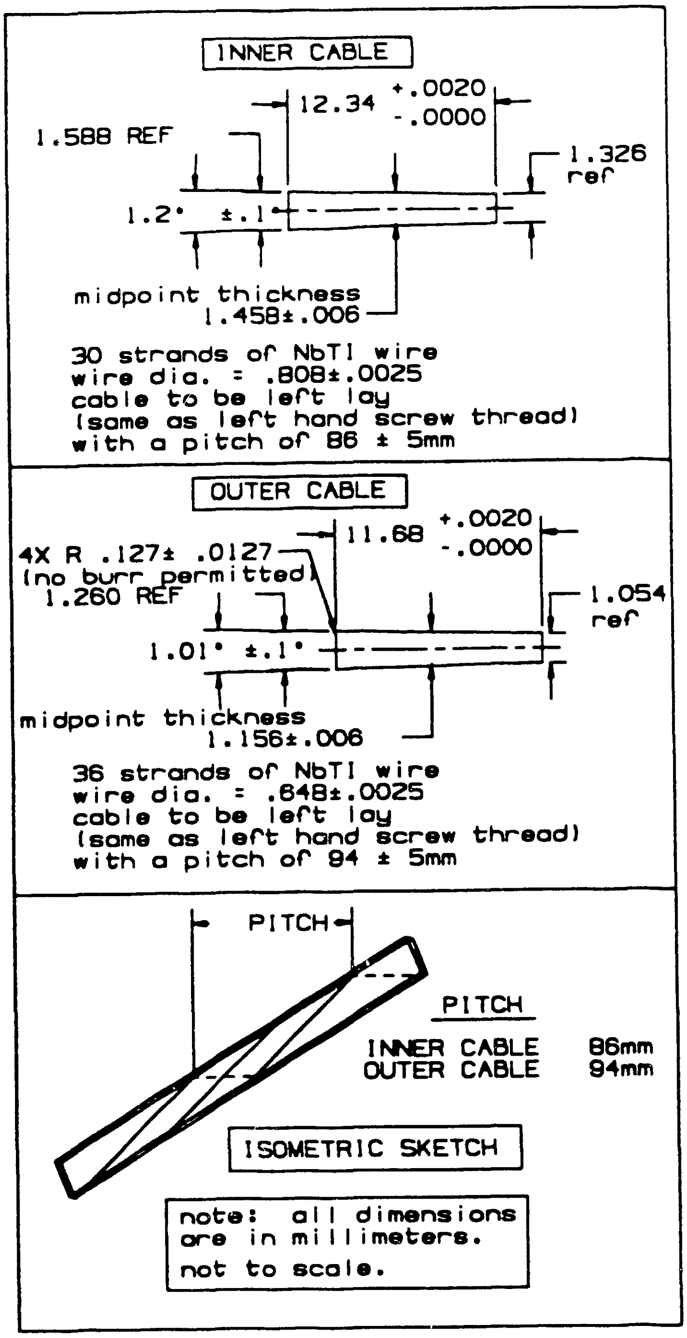


Figure 2. Schematic illustration of 50 mm SSC dipole cables, Inner and Outer

for Outer and 30 strands for Inner. The dimensional parameters are illustrated in Figure 2. The cable critical current (Ic) minimum is specified to be 10,152A for Outer and 9990A for Inner. Details of the sampling requirements and testing techniques are found in these cable specifications and in SSC-MAG-T-9001.

Strand Mapping Program

One way to enhance magnet performance and limit the variabilities of production is to "pick and choose" the individual strands when making a cable. Done effectively, this can increase the average Ic for an inventory of cable and narrow the window of variation between cables in this inventory. Until recently, this procedure called "strand mapping", has been done by hand based on piecelength. A computer program to automate strand mapping and increase our ability to compose a cable map based on individual strand lengths and their critical currents is now being incorporated into the cable manufacturing procedure. This PASCAL program reads an input file containing strand identification, length, and Ic. The operator is prompted for cable configuration, weld location information, and various cable manufacturing data such as the length needed for startup and sampling. The operator is also asked for the minimum and maximum Ic values desired in the cable before degradation effects. The program brings the cable Ic as close to the mean of this window as possible, without substantially increasing the number of welds. Strand placement is also based on weld location specifications and a 2 percent allowance for the difference between strand length and cable length. (This cabling allowance factor is a "rule of thumb" for 40 mm cable fabrication. A new cabling allowance factor for the 50 mm cable is being investigated.) Although revisions are inevitable, the first iteration of this program has already proved invaluable as a tool for cable manufacturing. In the future, the strand mapping program will help to narrow magnet-to-magnet performance variations.

Summary

Presently, 30 and 36 strand cable is being produced for the 50 mm Aperture Dipole Magnet Program. Current schedule plans require enough 50 mm cable to supply thirty-three 1.8 meter model dipole magnets as well as fifteen full size collider dipole magnets in 1991. This experience will give us a good base to work from as we move towards low and high rate SSC dipole production.

Acknowledgements

The authors thank M. Garber of Brookhaven National Laboratory for his work in cable sample testing. This work supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Department of Energy under Contract #DE-AC02-89ER40486.

References

1. R. Hannaford, D. Christopherson, R. Remsbottom, R. Scanlan, J. Royet, S. Graham, M. Boivin, "Resolutions to Difficulties Experienced in SSC Cable Fabrication During the Initial Scale-up Period", ASC Conference, Snowmass, CO, Sept. 24-29, 1990.

2. P.A. Sanger, for the Collider Dipole Magnet Task Force, "The Design of the Superconducting Super Collider Magnets", ASC Conference, Snowmass, CO, Sept. 24-28, 1990.

3. G. Morgan, S. Kahn, R. Gupta, "SSC Dipoles Having a 5cm Coil I.D. and Wide Cables", Magnet Division Note #340-1 (SSC-MD-242), Nov. 30, 1989.

4. SSC 50 mm Dipole Task Force Meeting Minutes, SSCL, March 21, 1990.

5. G. Morgan, W.B. Sampson, Brookhaven National Lab, SSC Note #SSC-N-519.

6. M. Green, DOE Workshop on Persistent Currents, Fermi National Lab, Batavia, IL March 1990.

7. J. Royet, R. Scanlan, "Development of Scaling Rules For Rutherford Type Superconducting Cables", ASC Conference, Snowmass, CO, Sept. 24-28, 1990.

END

DATE FILMED

11 / 14 / 91