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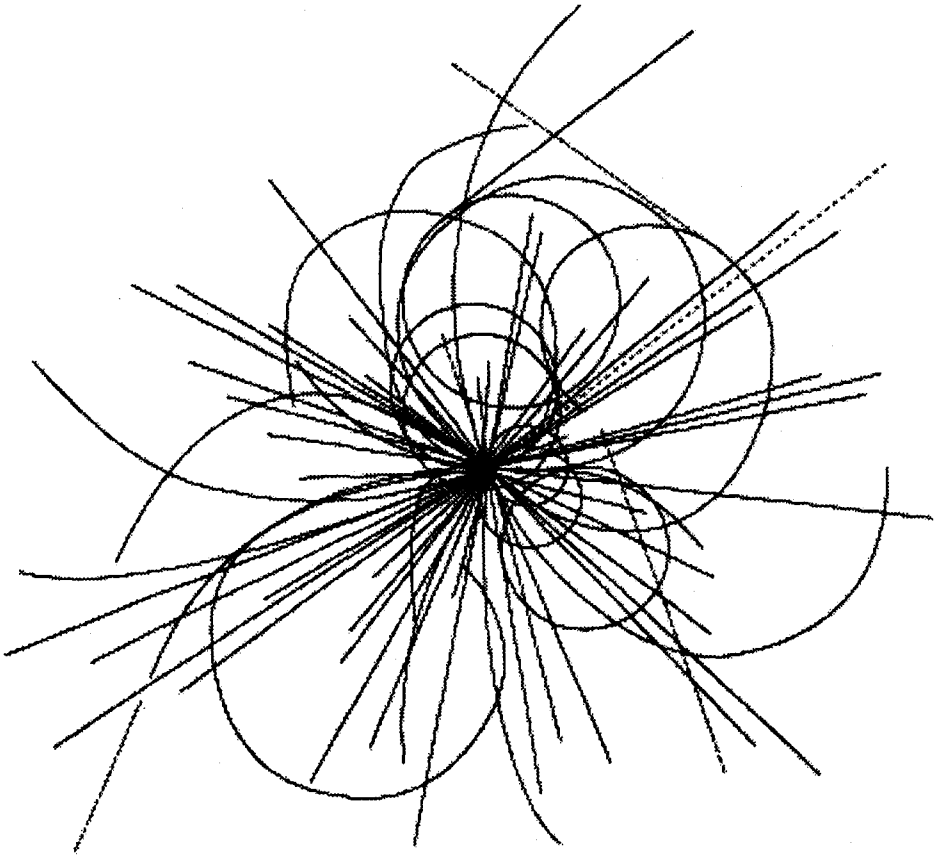

Superconducting Super Collider Laboratory

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FABRICATION AND AS-BUILT DESIGN OF THE 50 MM APERTURE SSC MODEL QUADRUPOLE MAGNETS

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INTRODUCTION

Three 50 mm aperture model quadrupole magnets, designated as QSE-101 through 103, have been built at SSC Laboratory, two of which have have been tested at 4.25 K. The original concepts for the magnet and tooling design as well as assembly procedures have been evaluated in this program. Throughout this process, several magnet components were modified to improve the performance, reliability, and manufacturing of the magnet. The original magnet assembly procedures and design specific tooling were also evaluated and modified to accommodate fabrication of the model magnet. Fabrication and redesign of the model quadrupole magnet has resulted in good magnet performance as well as a more reliable, cost effective, and more production oriented magnet and tooling design. The new concepts which have emerged and the lessons learned from this effort are being applied to the design of magnets and tooling for the SSC Interaction Region quadrupoles as well as other SSC magnets which may be fabricated at the SSC. In this paper a discussion of the magnet and tooling design modifications, assembly processes, and the lessons learned during assembly and evaluation of QSE-101 through 103 is presented.

QSE-101 THROUGH 103

A brief discussion of design modifications, assembly processes, and lessons learned during fabrication of QSE-101 through 103 is presented in this section. Major parameters and cross section of the magnet are presented in Table 1 and Figure 1, respectively.

Traditionally, SSC inner and outer coils are wound and cured separately and are then spliced together. Since both inner and outer coils are made of the same cable, the splice between inner and outer coils has been eliminated in QSE magnets. Prior to coil winding, the total conductor for an inner and outer coil is divided on two spools and the inner/outer coil ramp is formed. In the coil winding process the inner coil is wound and cured on the winding mandrel. An intercoil spacer, made of G-11CR and Kapton[1], is placed on the inner coil which serves as the winding mandrel for the outer coil. The outer coil is wound and cured as an assembly with the intercoil spacer and the inner coil. The major challenge for winding these spliceless coils involves handling of the outer cable spool during the winding

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of inner coils. In this process, the spool of the outer cable is suspended above the winding table and is allowed to rotate with the inner coil turns[2].

Table 1. Major magnet parameters.

Coil Inner Diameter	49.70 mm
Coil Outer Diameter	98.72 mm
Intercoil Spacing	0.55 mm
Coil End-to-End Length	1209 mm
Coil End Length	95 mm
Coil Straight Length	1019 mm
Inner/Outer Pole Angle	31.39 °
Inner Layer	——
Number of turns	11
Conductor blocks	8, 3
Number of wedges	1
Outer Layer	——
Number of turns	16
Conductor blocks	13, 3
Number of wedges	1
Collar Outer Diameter	140.40 mm
Yoke Outer Diameter	266.70 mm
Cold Mass Length	1.4 m
Cold Mass Diameter	276.5 mm

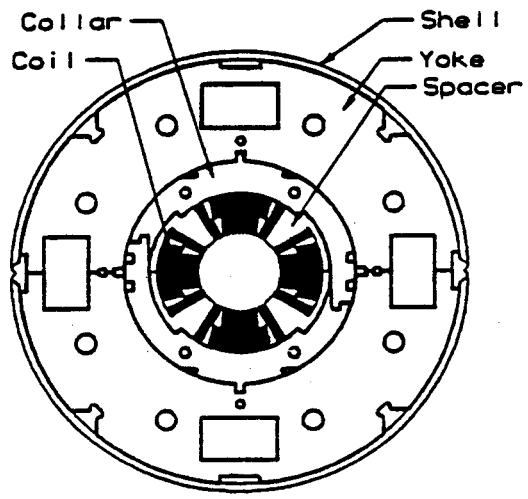

Figure 1. QSE cold mass cross section.

The inner radius of the QSE inner coil is 0.08 mm larger than that for the 50 mm aperture dipole magnet built at the SSC. The dipole coil winding mandrel was used to wind the QSE coils, lined with a 0.08 mm thick layer of Mylar[3]. This approach, which has been successfully implemented, saved the QSE program a considerable amount of time and money that would otherwise be required for fabrication of a new coil winding mandrel.

Inspection of QSE practice coils revealed separation of conductor blocks from adjacent coil end parts. This separation was more evident in the spacers and the fillers. The coil end parts had to be re-machined and re-molded to optimize the winding and to remove the improper turn placement after curing[2]. Particularly, the lead end filler part was reshaped using a new technique of shaping and molding with prepregs. The inspection of practice coils also revealed that the ramp between the inner and outer coils was too short. The lead end key, and the ramp forming process were modified to improve the configuration of the ramp. The short length of the ramp also resulted in a "dip" in the first turn of both inner and outer coils which are located at either side of the ramp. Experiments have indicated that increasing the length of the ramp solves this problem.

The cable used for winding QSE coils is a 36 strand cable, which is also used for winding SSC dipole magnet outer coils. This is a "left hand lay" cable. It has been determined that the left hand lay cable winds best clockwise and the right hand lay cable winds best counter clockwise[4]. Since the inner and outer coils are wound in opposite directions, one of them has to be wound in the "unfavorable direction". That is, the bend around the ends tightens the pitch of the cable which causes the strand to pop out of place. Typically, it is preferred to wind the inner coil in the favorable direction to avoid "strand popping". This is an important consideration, particularly since the tighter turn radius of the inner coil makes it more prone to the dangers of popped strands. The QSE inner coil is designed for counter clockwise winding, which is the unfavorable direction. A trial and error

process was required to determine an acceptable cable tension that was also suitable for manipulating the cable around the ends to insure the integrity of the cable. The problem with popped strands which appeared in the practice coils was resolved as the cable tension was adjusted and the coil winding technicians gained experience in handling the cable for this particular design.

The QSE coil azimuthal size was measured in the "deviation from the master" manner[2]. The inner coil is measured alone, after it is cured. Following the final cure of the inner/outer coil pair, the coils are measured as a pair. Ground insulation was added to the coil pair to duplicated the ground insulation in the magnet. Azimuthal coil size measurements for the practice magnet, QSE-101, and 102 indicated the inner coils to be 0.05 mm smaller and the inner/outer coil pairs to be 0.18 mm larger than the design size. The coil size deviation from design target values was due to deviation of coil curing tooling from the design. The coil curing approach uses the "fixed volume mold cavity" concept. Since all tooling parts have a fixed geometry, the coil azimuthal size is determined by the available volume between the sizing bars and the keys, which occupy the pole region, unless, shimming or another mechanism is used for adjusting the coil size. In an attempt to bring the outer coil size closer to nominal, a 0.20 mm thick shim was placed on top of the sizing bars for curing QSE-103 outer coils. The result was a reduction of 0.10 mm in coil size. Similar behavior has been observed in other magnet programs. Further coil size reduction was not attempted as indications of excessive stress appeared on coil end parts. The coil stress indicated by strain gage collar pack was considerably higher than the design target values for QSE-101 and 102. The coil stress in QSE-103 was very near the target values indicating the effectiveness of the attempt to reduce the coil size in 103. All three magnets used the same size collaring shims.

The ground insulation on coil ends was also modified to remove difficulties in assembly. The stepped cutouts in the end insulation were eliminated. Instead, parts of the straight section insulation were extended in to the ends and additional pieces of insulation were inserted in the ends. The ground insulation modifications still kept the insulation seams on successive layers in a staggered arrangement.

The spacer pack assembly design included using roll-pins to stack the laminations. These roll-pins were inserted into the holes of the stacked and aligned laminations using a tabletop arbor press. The longest available roll-pin for the specified holes in the spacer lamination was 30 mm long. This configuration, which was used for QSE-101, was determined to be ineffective and time consuming. QSE-102 and 103 used 160 mm long tubes with swaged ends for assembly of the spacer packs. This modification has considerably improved the assembly process. The strain gage blocks which have the same profile as the space laminations were 0.20 mm longer than the coil, causing concerns about interference at the mid-plane between top and bottom assemblies. The gage blocks were modified for QSE-102 and 103 by removing the excess material.

The collar laminations were about 0.1 mm smaller in the horizontal diameter and about 0.15 to 0.25 mm smaller on the vertical diameter due to fabrication error[2]. The collaring keys were about 0.08 mm smaller than the collar keyways, also due to fabrication error. Normally the smaller diameter of the collars would have caused a great concern. However, the vertical collar deflection after keys were inserted was considerably more than predicted by the finite element analysis that was performed in the design phase. The predicted and observed deflections of the collared coil are listed in Table 2. Limitations of the finite element model were determined to be the source of discrepancy between the predicted and observed collar behavior. The observed horizontal deflection is identical to that observed in dipole magnets. This was expected, despite predictions of the finite element model, since QSE magnets use dipole style collar laminations. The vertical collar deflection, however, is considerably larger than that observed in dipole magnets. The collar design has been modified for future 50 mm quadrupole magnets.

Table 2. Predicted and observed collar deflections of QSE-101 through 103

	Horizontal	Vertical
Predicted Collar Deflection, (mm)	0.11	0.12
Observed Collar Deflection, (mm)	-0.03	0.30

Due to use of separate pole spacers, QSE coils can not be assembled in the same manner used for assembly of conventional dipole and quadrupole coils. The QSE coils are assembled on a plastic mandrel which is removed after collar packs have been installed. In the coil assembly process the tooling holds the coils and the insulation as they are rolled over to insulate each quadrant[2]. This process is followed by installation of end ground insulation and collaring shoes. The spacer packs are installed and held in place by the tooling as the assembly is rotated to install spacer packs in each quadrant. Collar packs are the last components to be installed prior to keying of the collars, which is done in an identical manner to that used for keying of dipole magnet collars. The tapered collaring keys of the QSE magnet were inserted using a "square key" method. An approximately 50 % spring-back loss in coil stress has been observed when the vertical pressure from the press is removed.

Both the low carbon steel laminations and the stainless steel yoke laminations were stamped from the same die. Stamping and fineblanking experts agree that stainless steel laminations produced by a die that is made for stamping low carbon steel laminations are very likely to be distorted. Inspection of the QSE stainless steel yoke laminations revealed that the inner diameter of the stainless steel laminations was about 0.05 mm larger that the design size. This however, is thought to have been compensated for by the large vertical deflection of collar laminations. The stainless steel yoke laminations, used in the cold mass end yoke modules were to be epoxied to each other to prevent buckling of these laminations under press and welding loads. This process was not employed. Instead, the Stainless steel laminations were welded together after they were stacked and aligned in a fixture. In the welding process, filler material was not used and weld beads were made in locations were interference with adjacent or mating parts could not be caused.

The shell used in 40 mm dipole magnet was also used in QSE magnets. The arc length of the shell was reduced to make it compatible with the QSE alignment bars which are welded to the shells. The splice contour on the first splice plate which contains one of the three coil pair-to-coil pair splices, had to be modified to increase the hard bend radius, since the small bend radius caused the cable to collapse in first few attempts to form the cable.

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