Brookhaven National Laboratory
Associated Universities, Inc.
STAR Collaboration

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o Cognizant Engineer: _____
W.J. Leonhardt

o Approved by:

_____ _____
R.L. Brown W.R. Edwards

_____
K.J. Foley

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SPECIFICATION FOR STAR SOLENOID MAIN COILS AND SPACE TRIM COILS

1.0 General.

1.1 Summary.

This specification describes the Main Magnet and Space Trim Coils to be used as part of a large solenoid magnet detector system. This detector system is known as the Solenoidal Tracker at RHIC (STAR) and will be installed in the Relativistic Heavy Ion Collider which is a particle accelerator being constructed at Brookhaven National Laboratory.

The magnet consists of ten main coil assemblies and two space trim coil assemblies. The main coil assemblies are built up from four 2-layer pancakes and the space trim coils from two 2-layer pancakes. Each pancake is wound "two-in-hand" fashion with 13 turns connected in a manner which gives a total for the magnet of 572 turns in series electrically with 88 parallel water cooling circuits.

These coils will be incorporated within a thousand ton steel yoke and will contain sensitive apparata used in high energy and nuclear physics experiments. This detector system is a one-of-a-kind and must operate for long periods reliably. Consequently, this specification includes requirements for coil handling and manufacturing environment as well as detailing extensive electrical and mechanical tests during and following manufacture.

1.2 Scope.

This specification outlines the minimum requirements governing the design, materials, and testing of the main and space trim coils for the STAR detector. It should be read in conjunction with STAR Note #135, "Statement of Work for the Fabrication of STAR Solenoid Main Coils and Space Trim Coils."

2.0 Documents and Standards.

The following documents are an integral part of this specification:

2.1 Drawing List No. SDS-1 contains all drawing information relevant to the fabrication of these coils. This list is found in Appendix I.

2.2 Specification for STAR Solenoid Magnet Main Coil Aluminum Conductor, STAR Note #132.

2.3 Published Standards:

ASTM B193 "Standard Test Method for Resistivity of Electrical Conductors"
ASTM B236 "Standard Specification for Aluminum Bar for Electrical Purposes (Bus Bars)"
ASTM B324 "Standard Specification for Aluminum Rectangular and Square Wire for Electrical Purposes"

All standards shall be the latest revision available at the start of the contract.

3.0 Coil Parameters.

The STAR solenoid magnet is composed of ten Main Coils and two Space Trim Coils. Each coil is built up from individual two-layer pancakes. The pancakes are wound "two-in-hand" (bifilar) fashion with the crossovers being made as either a "right hand" or "left hand" helical winding. These pancakes are differentiated as either Pancake Coil Assembly "A" or Pancake Coil Assembly "B" and are alternated in the Main Coil and Space Trim Coil assemblies.

The following magnet parameters apply:

Design field	0.5T
Number of pancakes for Main Coil	4
Number of pancakes for Space Trim Coil	2
Number of layers/pancake	2
Number of turns/pancake (wound two-in-hand)	13
Conductor height	1.870 inch
Conductor width	2.120 inch
Conductor hole diameter	0.660 inch
Conductor corner radius	0.13 inch

Electrical resistance of a water circuit @ 68°F	0.00141 ohm
Electrical resistance of a pancake @ 68°F	0.00283 ohm
Electrical resistance of a Main Coil @ 68°F	0.01131 ohm
Electrical resistance of a Space Trim Coil @ 68°F	0.00566 ohm
Electrical resistance across entire magnet @ 68°F	0.1244 ohm
Water circuits/pancake	2
Water circuits/Main Coil	8
Water circuits/Space Trim Coil	4
Length of conductor/water circuit	387 ft.
Length of conductor/pancake	774 ft.
Voltage across entire magnet @ 68°F	590 volts
Design current through all turns *	4744 amps
Water flow/circuit @ 68°F	10.8 gpm
Pressure drop @ 11.1 gpm	100 psi
Water flow through entire magnet	950 gpm
Pancake nominal inner radius	104.371 inch
Pancake nominal outer radius	117.737 inch
Pancake nominal width	4.391 inch
Pancake weight	1.9 ton
Main coil nominal inner radius	104.331 inch
Main coil nominal outer radius	117.777 inch
Main coil nominal width	17.689 inch
Main coil weight	7.5 ton
Space Trim Coil nominal inner radius	104.331 inch
Space Trim Coil outer radius	117.777 inch
Space Trim Coil nominal width	8.877 inch
Space Trim Coil weight	3.8 ton
Coil weight for magnet	82.6 ton

* Space Trim Coils may carry 10% additional current.

4.0 Materials and Parts

4.1 Conductor.

The conductor shall be aluminum and in strict accordance with Specification STAR Note #132. It shall be electrical conductor grade type 1350-0 or type 1060-0 with maximum resistivity at 68°F of 1.098 micro-ohm-in, which corresponds to 61.8% IACS. The cross section of the conductor shall be:

Coil width 2.120 ± .010"
Coil height 1.870 ± .010"
Center hole 0.660" ± .010" diameter
Corner radius 0.13"

No field welds for splicing the conductor are allowed; the conductor shall be extruded in lengths sufficient to wind the approximately 400 feet per water passage without a joint. All press stops shall be marked and reels labeled with this information.

The minimum diameter of a spool drum for the aluminum shall not be less than 84 inches. Only one length (piece) of conductor material, wound on a single layer, will be placed on each reel. Both ends of the conductor shall be exposed enough to allow pressure tests and flow tests while the conductor is still on the reels.

4.2 Connections.

4.2.1 Electrical.

The electrical connecting lugs will be made of aluminum 6101-T6 or approved equivalent as shown on drawings MAG 111-E-1 through MAG 111-E-4 and MAG 112-E-1 through MAG 112-E-4.

4.2.2 Water.

The water cooling connections will be made using stainless steel fittings screwed into conductor bosses welded to the ends of each water passage. A detail of the boss is shown on drawing MAG 117-B-1.

4.3 Insulation.

4.3.1 Turn-to-Turn Insulation.

The combination of impregnating epoxy and Amino Silane treated glass fiber tape shall be used for the turn-to-turn insulation. The tape shall be 0.007 inches thick applied "half-lapped" to give a thickness of 0.014 inches and, after impregnating with the impregnating

epoxy, the combination shall have a minimum rated room temperature dielectric strength of 250 volts per 0.001 inch (volts per mil).

4.3.2 Inter-layer Insulation.

Prior to impregnating with epoxy, an additional layer of insulation shall be present between each layer of pancake and between each pancake. This layer shall consist of DMD70555 (Arlon Adhesives: Films Division) insulating sheet 0.015 inches thick.

4.3.3 Overwrap Insulation

The overwrap insulation shall be the same material as the turn-to-turn insulation described in Section 4.3.1 except that 0.010 inch thick material shall be applied half-lapped twice to give a total thickness of 0.040 inches.

4.3.4 Impregnating Epoxy Mix

The impregnating mix and curing cycle for vacuum encapsulation of the coils is as follows:

#DER 332 (Dow Chemical) DGEBA Resin; 50 p.b.w.

#DER 736 (Dow Chemical) Polyglycol Flexible Resin; 50 p.b.w.
and cured with
NMA (Allied Chemical Co.) Nadic Methyl Anhydride; 90 p.b.w.

Acceleration of cure shall be through the use of 1.5 p.b.w. DMP-30 (Rohm & Haas) Tridimethyl Amino Methyl Phenol.

The epoxy curing cycle shall take place at atmospheric pressure as follows:

180°F ± 5°F for 6 hours
260°F ± 5°F for 12 hours
Controlled cooldown to 140°F @ 20-25°F per hour.

During the curing cycle, all temperatures will be recorded and this record shall be included with the coil traveller.

4.3.5 Coil Leads

Each coil lead or "pigtail" shall have a portion insulated with BPTM-100/40 Au (Raychem) heat shrunk insulation as shown on drawings MAG 111-E-4 and MAG 112-E-4.

4.3.6 Filler Material

The filler pieces used on each pancake inside surface for the two-in-hand and layer-to-layer transitions shall be cast or machined in a fashion to insure uniformity of placement when winding on the turns. Additionally, all gaps between the conductor material and the outside of the coil package shall be filled with an approved epoxy impregnated glass fiber material.

5.0 Tests and Inspection.

5.1 Aluminum Conductor.

5.1.1 Before any aluminum conductor is wound into a coil it shall be tested in accordance with Specification STAR Note #132.

5.1.2 In the event that the tests described in Section 5.1.1 are performed at the conductor manufacturing location, an inspection will be performed at the winding facility to assure that no decrease in the conductor quality occurred during shipping.

5.2 Insulating Materials.

All insulating materials shall be inspected to determine their "shelf life" and to assure that they are used prior to the expiration of the shelf life. UNDER NO CIRCUMSTANCES shall material be used beyond its shelf life period.

5.3 Fluid Tests.

Following coil winding and all welding processes, the following fluid tests will be performed:

5.3.1 Pressure Test.

The ends of each water path will be sealed and the bore pressurized to a minimum of 375 psig with clean water. The water path shall be isolated from the pressure source and the pressure in the bore monitored for one hour. Any loss of pressure other than due to temperature change effects shall be deemed a test failure. The result of this test shall be recorded as outlined in Section 5.8.

5.3.2 Flow Test.

Each water path shall be tested to flow at least 10.3 gallons per minute of 68°F water with a pressure drop between the inlet and outlet of no more than 100 psig. The result of this test shall be recorded as outlined in Section 5.8.

Immediately following the fluid tests, the bore will be blown dry and will be sealed with suitable caps.

5.4 Electrical Tests.

5.4.1 Turn-To-Turn Tests.

Prior to and following epoxy impregnations, adjoining water paths shall be tested by applying a minimum of 200 volts DC between them and measuring leakage current. A leakage current greater than 25 microamps is a test failure. In a similar manner, a minimum of 400 volts DC shall be applied between pancakes prior to and following impregnation and the leakage current measured. A leakage current greater than 25 microamps is a test failure. These tests will be accomplished prior to electrically joining all water paths and pancakes. The whole coil turn-to-turn test shall be proposed by the vendor in his fabrication procedure and approved by the Buyer. The test shall be performed a.) on each pancake following winding but before curing the epoxy; b.) on each coil assembly after the final epoxy cure. Results of the final turn-to-turn test shall be recorded as outlined in Section 5.8. Results of tests performed prior to the final test shall be recorded on the coil traveller.

5.4.2 Ground Test.

The ground test shall be proposed by the Seller in his fabrication procedure and approved by the Buyer. Ground tests shall be performed on each pancake after curing of the epoxy. The test must apply at least 4000 volts DC between the conductors and ground. A leakage current greater than 100 microamps is a test failure. Results of the ground test shall be recorded as outlined in Section 5.8.

5.5 Electrical Conductivity Tests.

The electrical conductivity of each conductor shall be determined by measuring resistance end-to-end:

- After completing the winding of each pancake the resistance of each water circuit shall be measured. A resistance at 68°F or equivalent of more than 0.00144 ohms is a test failure. The results of the conductivity test shall be recorded as outlined in Section 5.8.

- Upon completion of coil assembly, the resistance of the coil shall be measured end-to-end. A resistance of more than 0.0115 ohms at 68°F for a Main Coil, or 0.00574 ohms at 68°F for a Space Trim Coil or equivalent, is a test failure. The results of the conductivity test shall be recorded as outlined in Section 5.8.

5.6 Dimensional Checks.

All dimensional checks and measurements shall be made with the items being measured and the instrumentation at 68°F else temperature effects shall be considered.

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The Seller shall inspect each coil after the final epoxy cure for compliance with the appropriate drawing dimensional tolerances. Non-compliance with drawing dimensional requirements is a test failure and grounds for coil rejection.

The results of the dimensional checks shall be summarized as outlined in Section 5.8. Additionally, the Seller shall mark up a copy of the appropriate drawing for each coil assembly with the "as built" dimensions recorded. The coil serial number must be on these drawings.

5.7 Obstruction Test.

Following all fabricating procedures, the bore of each water path shall be tested to be free of obstructions by passing a ball of 0.500 ± 0.005 inch minimum diameter through its entire length. The results of this test shall be recorded as outlined in Section 5.8.

5.8 Test Records.

An inspection report shall be prepared for each coil assembly. This report shall record all test results, the name of the person performing the test, test date and test outcome. As a minimum, the report shall include:

Coil Name (Main or Space-Trim)
Coil Assembly Drawing Number and Revision Letter
Coil Serial Number
Results of Conductor In-coming Inspection
Serial Numbers of Conductor Lengths used in this coil
Results of Pressure Test
Pressure drop and flow rate data for each water path. Also test water temperature
Turn-to-Turn Test
Ground Test Data including Test Voltage and Leakage Current
Electrical Conductance and resistance of each water path
Electrical Conductance and resistance of coil
Results of Dimensional Check
Results of Obstruction Test

6.0 Markings.

Prior to shipment, the Seller shall mark and identify each coil assembly by drawing number and revision letter, Seller's name, and a unique serial number generated by the Seller. This information shall be painted with white epoxy paint in the location as specified in the drawings. No other permanent markings may be applied without the approval of the Buyer.

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APPENDIX I

DRAWING LIST NO. SDS-1

Title	Number
Main Coil Assembly	MAG100-E-1
	MAG100-E-2
	MAG100-E-3
Pancake Coil Assembly "A"	MAG111-E-1
	MAG111-E-2
	MAG111-E-3
	MAG111-E-4
Pancake Coil Assembly "B"	MAG112-E-1
	MAG112-E-2
	MAG112-E-3
	MAG112-E-4
Aluminum Coil Conductor	MAG113-B-1
North Pancake Conductor Jumper	MAG116-B-1
Aluminum coil Conductor Bus	MAG117-B-1
Pancake-to-Pancake Bus	MAG118-B-1
Space Trim Coil Assembly	MAG150-E-1
	MAG150-E-2
	MAG150-E-3