U.S. HL-LHC Accelerator Upgrade Project

SPECIFICATION FOR

QUADRUPOLE MAGNET CABLE INSULATION

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Revision History

Rev.	Date	Description	Section	Preparer
A	06-Mar-14	Original Release		A. Ghosh
B	01-Dec-15	Updated cable parameters according to 2nd generation design; updated vendor procedure and FNAL drawing in the appendices according to their latest releases; clarified glass fiber twist direction; formatted using MS Word Styles		I. Pong
C	02-May-18	Converting LARP-MAG-R-8006 Rev B to U.S. HL-LHC AUP specification format. Removed Appendix D, the new vendor procedure will now be available at the vendor location. Included single-ply option. Included new carrier number options. Gave the vendor the authority to adjust the machine settings if 10-stack measurements are out of spec. New section on surface conditions. Included the option of adding a ring of corrugated PE for protection at the flanges. New Figure 1. New section on QC/QA New drawing for Appendix C. Removed redundancies and added insulation material details	Full document Appendix section 4.2 4.4.1 4.4.2 4.4.3 4.4.4 4.4.4 5 Appendix C	C. Sanabria
D	21-June-2018	Updated document name from US-HiLumi-doc75 to HL-LHC AUP-Doc. 75 A take-up tension lower limit is now specified. Updated shipping protective measures. Corrected drawing revision typo in identification requirements	Tile & header 4.4.4 4.4.4 6.3	C. Sanabria

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1 SCOPE

This specification establishes and defines the requirements for the electrical insulating material applied to the Rutherford cables (18.15 mm x 1.525 mm) used for HL-LHC AUP QXF magnet coils. AUP will supply the superconducting cable. The vendor shall provide, or otherwise procure, all additional material, certifications, personnel, and all other associated facilities necessary to fabricate, inspect, test, package, and ship the insulated material as specified herein, unless otherwise agreed or authorized by AUP.

2 APPLICABLE DOCUMENTS

The following documents (Appendices) form a part of this specification to the extent specified herein:

- AGY S-2 Glass® Direct Sized Yarn Product Document No.: TP-379.
- FNAL Engineering Drawing F10043195.

3 PROCESS MATERIALS

The following process or magnet materials are referenced for use in this procedure and shall be controlled for procurement, use, storage, and handling by the documents listed below. Substitutions require prior LBNL written approval.

Table 1 Process materials and source.

Material	Source
S-glass 933 S-2 Glass® SCG 75 1/0 0.7Z	AGY 2558 WAGENER ROAD, AIKEN, SOUTH CAROLINA, USA 29801.

4 REQUIREMENTS

4.1 General

Any and all conflicts among the requirements listed in this specification are to be brought to the attention of the AUP technical representative for resolution prior to the commencement or continuation of work. Under no circumstances is the vendor to take any initiative without this resolution.

4.2 Insulation Material

The insulation material shall be S-2 Glass® fiber identified as SCG 75 1/0 0.7Z fiber with 933 sizing.

A 2-ply yarn of this is to be used for braiding. The 2-ply yarn shall have a twist pitch of 3 inches in the S direction (*i.e.* opposite to the fiber twist direction which is Z). The nomenclature for the glass being applied to the cable is SCG 75 2/0 0.3S with 933 sizing. Single-ply yarn may be used

if the number of carrier is doubled to achieve the same build. The nomenclature for the glass being applied to the cable is then identical to the fiber itself (see Table 1).

No changes to the abovementioned specifications are allowed without written approval from AUP.

4.3 Handling

Insulated cable must be handled with care during fabrication, packing, shipping and usage so as not to damage the insulation and/or wire.

4.4 Procedure

4.4.1 Braiding of Insulation

The cable is to be insulated by braiding the glass yarn using a 48-carrier braiding machine (if the 2-ply yarn described above is used), or a 96-carrier braiding machine (if the single-ply yarn is used). It is possible to perform the insulation with a 32-carrier braiding machine using non-twisted 2-ply yarn, provided prior written approval from AUP is obtained.

The QC systems described below in Section 5 must track the entire braiding process. The braiding process must be stopped whenever any of the detectors are triggered. Additionally, the tensioning mechanism (take-up) must be energized at all times throughout the insulation run to avoid braid tension surges[1].

The braiding process is controlled by the vendor's operating procedure, a copy of which is kept at the vendor location. Any updates to this procedure must be reported to AUP and written AUP approval of the changes must be obtained before the change is implemented.

4.4.2 Insulation Thickness

The insulation thickness of the first five feet of braided cable is measured prior to insulating the remaining length. This measurement is to be done by the vendor using a 10-stack measurement device as detailed in **Appendix A: 10-Stack Measurement Procedure**, or an approved equivalent.

If the 10-stack measurement shows that the insulation thickness is 0.145 ± 0.005 mm, the vendor is to insulate and cut another five feet of cable[2]. After cutting this verification sample, the remaining length of cable is to be insulated as described in Section 4.4.1.

If the thickness of the first 10-stack measurement is outside the tolerance, the vendor may adjust the machine parameters to increase or decrease the thickness based on their experience. Once the adjustments are made, the vendor may insulate another 5 feet of cable and produce another 10-stack measurement. After a second 10-stack measurement, if the insulation is within specification, the vendor may insulate and cut the AUP's verification piece (5 ft) and the remaining length of cable is to be insulated as described in Section 4.4.1. If the second 10-stack measurements fail to meet specification, the vendor must stop work and bring this to the attention of the AUP tehcnical representative for resolution prior to commencing further work.

Under no circumstances the total length of the 10-stack samples (supplier 10-stack samples+ verification sample) should exceed 5 m unless there is a written approval by AUP.

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[1] An exception may be whenever cuts are performed (*i.e.* 10-stack samples)

[2] This second 5 ft sample is to be sent to the AUP technical representative for 10-stack measurement verification. It may be preferable for both 5 ft pieces (supplier 10-stack sample and verification sample) to be braided in a single run—which would require stripping the braid off if the 10-stack measurement fails, but may provide more homogeneous samples.

4.4.3 Insulation Surface Condition

As delivered to HL-LHC AUP, insulation artifacts such as oil spots and other foreign material, as well as frayed edges, tears, exposed edges, and other defects, must be as low as reasonably achievable. The examination method and reporting of these instances are described below in Section 5.

4.4.4 Spooling Requirements

The cable must be spooled so there are no crossovers of the cable windings. A minimum take-up tension of 12 lbs must be used, and protection rings made of soft, non-abrasive polyethylene foam (1/4 inch thick) should be attached to the inside of the spool flanges in order to protect the cable insulation from wearing due to repeated rubbing against the flanges during shipment. Padding between the crate and the spool is also recommended to dampen vibrations.

For required spooling direction, see Figure 1.

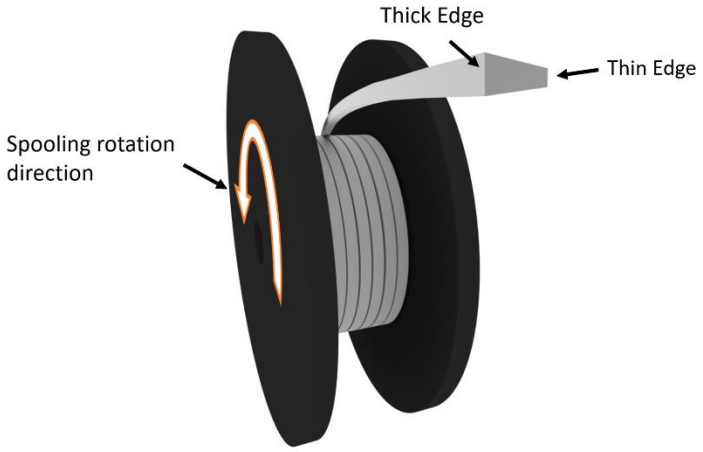

Figure 1 Cable spooling direction

4.4.5 Reels/Spools

The cable must be spooled on HL-LHC AUP-approved reels with a minimum hub diameter of 12 inches, flange diameter of 24 inches and minimum width of the hub of 6 inches. The spools must be constructed to prevent damage to the cable during spooling and unspooling. The spools are to be supplied by AUP unless otherwise agreed in writing.

5 QUALITY ASSURANCE AND QUALITY CONTROL

5.1 Quality Control Systems

The entire insulation process must be subjected to various real-time QC processes including:

- An imaging system for detection of insulation artifacts such as oil drops[3] and poor insulation coverage,

[3] If oil drops are observed by the imaging system, the operator is to attempt to clean the oil with a cotton swab and ethanol.

- A low-voltage system acting on all four sides of the cable for detection of foreign material and poor insulation coverage, and
- A dimension-tracking system for detection of popped strands and cable "roping"[4].

5.2 Quality Assurance Provisions

Any instances where the machine stops for any reason must be recorded and reported. The following comments are to be added to the entries depending on the nature of the stoppage:

Table 2 Comments added to the insulating map report depending on the reason for the stop.

Nature of stop	Reason	Comment
Procedure stop	Feed in	Feed in
	End of shift	End of shift
	Cleaning	Cleaning
	Other process stops	Process stop
Imaging system stop[5]	False positive – oil reading	Vision Oil False
	Successfully cleaned oil spot	Vision Oil Cleaned
	Unsuccessfully cleaned oil spot	Vision Oil Still There
	False positive – poor insulation coverage reading	Vision Copper False
	Poor insulation coverage (wire surface observed)	Vision Bare Wire
	False positive – frayed insulation	Vision Edge Tool False
	Frayed insulation	Vision Edge Tool Frayed Edge
Low voltage system stop	False positive – bare cable	Voltage Copper False
	Bare cable detected	Voltage Bare Cable
	Foreign material detected	Voltage Foreign Material
Dimension system	False positive – Collapsed (roped) cable	Collapsed Cable False
	Collapsed (roped) cable detected	Collapsed Cable

6 PREPARATION FOR DELIVERY

6.1 Packing

The insulated cable is to be packed in the equivalent way it is received. First, the spools are strapped to a pallet with the spool flanges maintained in a vertical orientation (axes horizontal) in order to prevent the cable from settling on the spool. The pallet is then boxed and sealed.

6.2 Documentation

The following documentation is required from the vendor:

[4] If the dimensional changes are due to a popped strand, the operator may attempt to carefully put the strand back in place. If the cable collapses, the vendor must stop work and notify AUP technical representative for a resolution before proceeding.

[5] If the imaging system detects a positive reading, the image of such instance must be supplied to the AUP technical representative.

- 10-stack measurement data in electronic form.
- Carrier Spool tension.
- Payoff Spool tension.
- Take-up Spool tension.
- Cable Insulating Map specifying the instances when the insulation was started or stopped including:
  - The footage counter value of the instance
  - The date and time.
  - The comments outlined in Table 1.
- Non-conformance Reports.
- Total length of braided cable per the same footage counter value, unadjusted.

6.3 Marking/Identification Requirements

Spools and exterior packaging shall be identified with the following information in the order shown:

Superconducting Insulated Cable for
QXF Magnet Coil
Procedure No: HL-LHC AUP-Doc. 75 - Rev. D
FNAL Drawing Number: F10043195-D-RCD
Buyer P.O.
CABLE ID.
Length: _____ft. or _____ m
Weight: _____lbs. or _____ kg
Date of Insulating:
Name of Insulator:

7 APPENDIX A: 10-STACK MEASUREMENT PROCEDURE

1. Start with a section of cable about 70 inches long.
   1.1. Mark one edge of the entire length of the cable with a Sharpie.
   1.2. Using Kapton tape or equivalent, tape off 10 sections of the insulated cable each six inches long.
   1.3. Make 9 cuts through the center of the tape to get 10 sections.
2. Select the boat and top pusher with the proper width.
   2.1. **Boat width for QXF cables is 18.65 mm (**Side plates need to be at least 0.2 mm wider than the insulated cable to be measured).
   2.2. **The top pusher width** should be smaller than the cable width and greater than 17.5 mm).
3. Insert the reference block into the boat and then insert the boat into the press.
   3.1. Close the main valve and pump the system to the gauge equivalent value which correspond to 5 MPa of pressure on the reference block and zero the LVDT transducers. (Verify the gauges are set to mm.)
   3.2. Remove the boat. Use caution when removing or installing the boat as not to disturb the gauges.
4. Insert the insulated cable sections into the boat.
   4.1. Verify that the pieces are stacked so that the edges are alternating.
   4.2. Place the boat into the press.
5. Close the main valve and begin pumping. Stop at the pre-determined gauge equivalent pressure which corresponds to 5 MPa of pressure on the cable stack. Record the measurement. Use the needle valve near the pressure gauge to hold the pressure while taking measurements. Make sure the pressure is stable before taking measurements.
6. Repeat step 5 three times.
7. Remove the boat and the insulated cable sections. Re-verify zero of the LVDT transducers using the reference block in the boat.
8. Remove the insulation from the cable sections. Mark the edge of the bare cable that corresponds to the insulation cable. Re-stack them in the boat. Verify once again that they are stacked alternately.
9. Repeat steps 5, 6 and 7 for the bare stack.
10. Determine the average of the 3 measurements of the insulated cables.
11. Determine the average of the 3 measurements of the bare cable.
12. Subtract the insulated average from the bare cable average and divide by 2 to obtain the insulation thickness per side.

Record all measurements in the work sheet. If the average of the three readings is within specification, the 10-stack measurement is acceptable. If one of the three measurements is outside the specification, the AUP tehcnical representative should be notified, but the vendor may proceed so long as the average is within spec.

8 APPENDIX B: AGY S-2 GLASS®

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CUSTOMER ACCEPTANCE STANDARD

No.: TP-379
Date: 18 Jun 10
Supersedes: 25 May 07
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S-2 GLASS® HIGH TENSILE STRENGTH GLASS DIRECT SIZED YARNS

I. DESCRIPTION

This is an S-2 Glass® High Tensile Strength Fiberglass yarn bundle composed of numerous continuous glass filaments gathered with mechanical twist and treated with direct size chemistry, with matrix compatibility as listed below. *S-2 Glass* yarn is a high silica glass fiber with superior mechanical strength, impact strength, stiffness, fatigue resistance, radar transparency, and thermal resistance for demanding applications. The product meets the requirements of MIL-Y-1140H and ANSI/IPC-SG-141 as they pertain to the input yarns of glass fiber fabrics. This yarn is produced at an ISO 9001-2008 certified production plant.

II. USE

S-2 Glass Yarns are principally used for further fabrication, such as plying, winding, braiding, weaving and serving.

III. YARN NOMENCLATURE

Example Product Name (US Customary System)	Example Product Name (SI System)
SCG75 1/0 1.0Z	SC9-66 1x0 Z40
S - High strength glass formulation	S - High strength glass formulation
C - Continuous filaments	C - Continuous filaments
G - Filament diameter (See Table 1)	9- Filament diameter (See Table 1)
75- Yards per pound divided by 100	66- grams per 1000 meters of yarn
1/0- Single yarn end	1x0 - Single yarn end
1.0Z - Turns per inch (TPI) twist (Z or S)	Z40 - Turns per meter (TPM) twist (Z or S)

Throughout history, the actual yardage or tex of yarn products has often been shifted from the actual yield provided in the product name. Therefore, the yarn name is only used as a descriptor. The table in Section V must be utilized to obtain the actual bare glass yield of a yarn product.

IV. GENERAL INFORMATION

Reference Textiles Fibers For Industry for more information

Filament Designation		Range for Filament Diameter Average			
US Units (letter)	SI Units (microns)	Minimum (inches)	Maximum (inches)	Minimum (microns)	Maximum (microns)
G	9.0	0.00035	0.000399	8.89	10.15

- Filament diameter is for reference purposes. Yarns are controlled according to yield/tex.

V. AVAILABLE PRODUCTS AND BARE GLASS PROPERTIES

Product Nomenclature*		Sizing	Bare Glass Yield**					
			yd./lb.			TEX		
US Customary System	Tex/Metric System (SI)		Min	Nominal	Max	Min	Nominal	Max
SCG 75 1/0 1.0Z	SC9-66 1x0 Z40	493	6,914	7,500	8,086	61.3	66.1	71.7
SCG 75 1/0 0.7Z	SC9-66 1x0 Z28	933	6,644	7,500	9,212	53.8	66.1	74.7
SCG 150 1/0 1.0Z	SC9-33 1x0 Z40	493	13,750	15,000	16,250	30.5	33.1	36.1

*- Nomenclature used for identification purposes only. Nomenclature may not indicate true yield.

This specification is subject to change without notice. S-2 Glass® is a registered trademark of AGY

9 APPENDIX C: FNAL ENGINEERING DRAWING F10043195-D-RCD