ii. Superconductor

30-Strand Superconducting Cable

The 30-strand (or wire) superconductor cable is used in the fabrication of all of the dipole and quadrupole magnets with 8 and 10 cm aperture. A similar cable has been fabricated and used for many years in the RHIC and in the SSC 40 mm R&D programs. Consequently, the wire and cable fabrication methods are well developed. During magnet fabrication the cable will be insulated just prior to use for winding coils.

The dimensional, mechanical and electrical properties of the superconducting strand used to fabricate the cable are summarized in Table 1-2. Each strand consists of 3510 Nb-Ti alloy superconducting filaments with nominal diameter of 6μm and spacing >1μm. The exact number of filaments has been chosen by the superconductor vendor based on the details of the billet design, and will be maintained within ±20 for every billet assembled. Copper is used as the matrix between filaments, it occupies a >10% cross section central core, and provides an outer covering for the wire. Copper represents about 69% of the wire cross section and is important for the cable and magnet operational stability. The wire diameter of 0.648 mm is tightly controlled during final stages of manufacturing and is checked with a laser micrometer.

The wire minimum critical current is defined at a temperature of 4.22 K, an applied magnetic field of 5.0 T perpendicular to the wire axis and a resistivity of 1×10^{-14} Ω·m based on the total wire cross section. This current requirement corresponds to a minimum current density in the Nb-Ti superconductor of 2600 A/mm^2 at 5.0 T. This modest requirement was chosen for the RHIC magnets because higher values were unnecessary to meet the accelerator design objectives, and because the emphasis for superconductor manufacturing is being placed on uniformity of wire and cable properties. In manufacturing, about 2800 A/mm^2 is being achieved. An upper limit is placed on wire critical current at 3.0 T in order to control the effects of superconductor magnetization at injection.

Thirty wires are fabricated into a Rutherford-type cable by first twisting them around a "mandrel" and then immediately rolling them into a flat, keystoned shape with dimensions given in Table 1-3 and Fig. 1-1. The variations of the cable dimensions, especially the cable mid-thickness, are tightly controlled because the magnetic field quality of the magnets and the coil prestress are strongly dependent on them. The cable lay (or twist) pitch is chosen to be opposite to the wire twist and requires a cabler operating in a planetary mode for fabrication. The cable minimum critical current (see Table 1-3) is defined in a similar way to that for the wire, but with the magnetic field perpendicular to the wide surface of the cable and with compensation for self-field. The cable minimum critical current can be obtained from the " wire minimum critical current at 5.0 T " times 30 (number of wires in cable) and multiplying by 0.95 (allowance for 5% degradation in cabling). All cable lengths will be produced without cold welds.

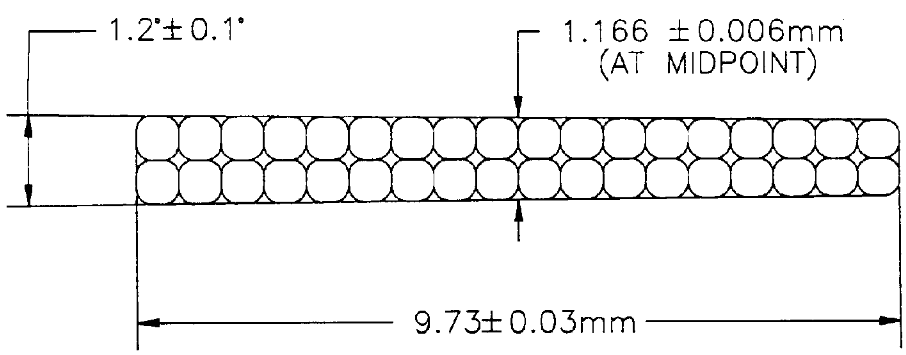

Fig. 1-1. Cross section of the cable to be used to fabricate coils for RHIC dipole and quadrupole magnets with 8 cm aperture and the 10 cm D0 dipole.

Table 1-2. Wire Requirements for 30-Strand Cable

Requirement	Value	
DIMENSIONAL AND MECHANICAL		
Nominal Filament Diameter	6	μm
Nominal Filament Spacing	>1	μm
Nominal Copper to Non-Copper Ratio	(2.25±0.1):1	
Number of Filaments	3510±20	
Wire Diameter	(0.0255±0.0001 in.) 0.648±0.003	mm
Wire Twist Direction	Right	
Wire Twist Pitch	(1.9±0.2 twists/in.) 0.75±0.08	twists/cm
ELECTRICAL		
Wire Minimum Critical Current at 5.0 T, 4.2 K	264	A
Wire Maximum Critical Current at 3.0 T	1.6 × measured I_{crit} @ 5.0	T
Wire Maximum R(295 K)	0.0765	Ω/m
Wire Minimum RRR	38	

Table 1-3. 30-Strand Cable Requirements

Requirement	Value	
DIMENSIONAL AND MECHANICAL		
Number of Wires in Cable	30	
Cable Mid-Thickness	(0.04590±0.00025 in.) 1.166±0.006	mm
Cable Width	(0.383±0.001 in.) 9.73±0.03	mm
Cable Keystone Angle	1.2±0.1	deg
Cable Lay Direction	Left	
Cable Lay Pitch	(2.9±0.2 in.) 74±5	mm
Wire Twist Pitch in Cable	(1.9±0.2 twists/in.) 0.75±0.08	twists/cm
ELECTRICAL		
Cable Minimum Critical Current at 5.0 T, 4.2 K	7524	A
Cable Maximum R (295 K)	0.00268	Ω/m
Cable Minimum RRR	38	

36-Strand Superconducting Cable

The insertion quadrupole and dipole magnets with 13 and 20 cm apertures respectively have a single-layer coil. While considering the design alternatives, it was decided to take advantage of superconductor wire and cable which were well-developed for another, similar magnet program. The conductor chosen was that now being used for outer-layer coils of the SSC Collider Dipole Magnet with 50 mm aperture.

The dimensional, mechanical and electrical properties of the strand (or wire) used to fabricate the cable are given in Table 1-4. The copper-to-non-copper ratio of 1.8:1 requires that the number of Nb-Ti superconductor filaments be approximately 4100, with the exact number to be chosen by the vendor in final billet design. Copper represents 64% of the wire cross section. The filament diameter of 6 μm and spacing of >1 μm are standard parameters for wires of this type to control low field magnetization and coupling. As for most twisted wires, a central copper core is required with >10% cross section.

The critical current characteristics of the wire are given in Table 1-4; for the 36-strand cable they are given in Table 1-5. The minimum critical currents are defined at a temperature of 4.22 K, a magnetic field of 5.6 T and a resistivity of 1×10^{-14} Ω·m. The critical current requirement of the wire corresponds to a minimum current density in the superconductor of 2750 A/mm^2 at 5.0 T or 2420 A/mm^2 at 5.6 T, both without self-field effects. The cable critical current allows for 2% degradation during cabling and includes self-field effects.

The cable dimensional requirements given in Table 1-5 and Fig. 1-2 for the most part correspond exactly to what is being fabricated for SSC. Cable with keystone angle of 1.0^{o} will be used for RHIC 13 cm aperture quadrupoles; this is the angle chosen for SSC magnets. A smaller keystone angle of 0.6^{o} will be used for the RHIC 20 cm dipole. The cable is fabricated in a "planetary" mode, where the original twist of the wire is preserved during the cabling operation. All cable lengths will be produced without cold welds.

Table 1-4. Wire Requirements for 36-Strand Cable

Requirement	Value	
DIMENSIONAL AND MECHANICAL		
Nominal Filament Diameter	6	µm
Nominal Filament Spacing	>1	µm
Nominal Copper to Non-Copper Ratio	(1.80±0.1):1	
Number of Filaments	(4100 - 4200)±20	
Wire Diameter	(0.0255±0.0001 in.) 0.648±0.003	mm
Wire Twist Direction	Right	
Wire Twist Pitch	(1.9±0.2 twists/in.) 0.75±0.08	twists/cm
ELECTRICAL		
Wire Minimum Critical Current at 5.6 T, 4.2 K	286	A
Wire Maximum R(295 K)	0.0827	Ω/m
Wire Minimum RRR	36	

Table 1-5. 36-Strand Cable Requirements

Requirement	Value	
DIMENSIONAL AND MECHANICAL		
Number of Wires in Cable	36	
Cable Mid-Thickness	(0.04550±0.00025 in.) 1.156±0.006	mm
Cable Width	(0.460+0.002/-0.000 in.) 11.68+0.05/−0	mm
Cable Keystone Angle - 13 cm quadrupoles	1.0±0.1	deg
- 20 cm dipoles	0.6±0.1	deg
Cable Lay Direction	Left	
Cable Lay Pitch	(3.7±0.2 in.) 94±5	mm
Wire Twist Pitch in Cable	(1.9±0.2 twists/in.) 0.75±0.08	twists/m
ELECTRICAL		
Cable Minimum Critical Current at 5.6 T, 4.2 K	10100	A
Cable Maximum R(295 K)	0.00240	Ω/m
Cable Minimum RRR	36	

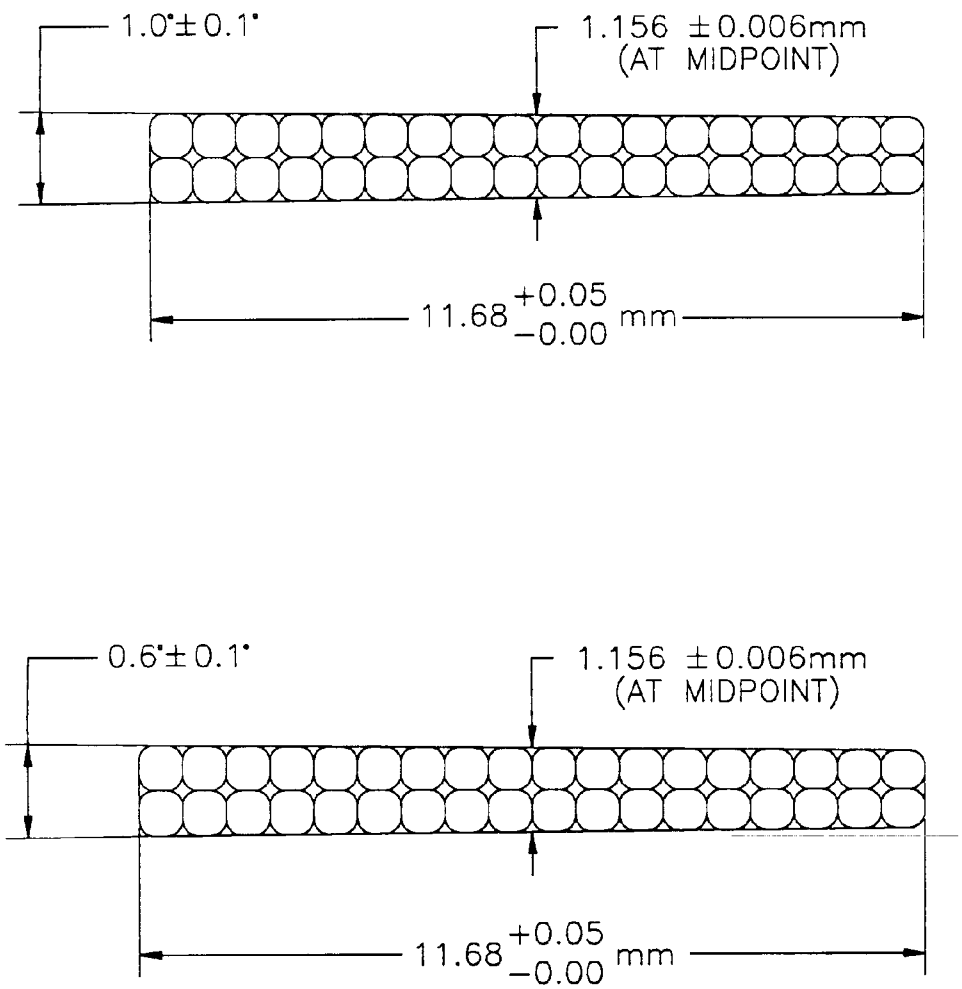

Fig. 1-2. Cross sections of the cable to be used to fabricate coils for RHIC insertion quadrupoles with 13 cm aperture (1° keystone angle) and insertion dipoles with 20 cm aperture (0.6° keystone angle).

Sextupole, Trim Quadrupole and Corrector Wire

The same wire will be used to fabricate coils for the sextupole and trim quads and a similar wire for the corrector magnets. It should be noted that the coils are wound from insulated wire, not from cable, and, therefore, the integrity and uniformity of the wire along the length is extremely important for the operation of the magnets. The magnets and superconductor are designed with considerable margin between the expected operating current, in order to raise confidence in the operating reliability.

The dimensional, mechanical and electrical properties of the superconducting wires for the sextupole and corrector magnets are summarized in Table 1-6. The nominal filament diameter of 10 μm is somewhat larger than that for RHIC cable magnets, but this reflects a reduced concern about magnetization effects in these magnets. The nominal copper-to-non-copper ratios of 3.0:1 and 2.5:1 are based on experience from RHIC R&D magnets. The wire diameters of 0.508 and 0.330 mm were chosen in order to accommodate the necessary insulation in the design coil space (to be applied later) and because wires of these diameters match the desired operating currents. The 0.33 mm (plus insulation) wire for the corrector is the maximum size usuable in the Multiwire machine.

The wire minimum critical current is defined at the standard values of 2.0 T magnetic field, 4.22 K temperature and at a resistivity of 1×10^{-14} Ω·m over the total cross section of the wire. The wire is to be delivered with the copper in the annealed state to enhance wire ductility and to facilitate coil winding. Careful eddy current testing will be done over the full length of all delivered wire to eliminate any wire sections with inclusions which may locally damage the superconductor filaments and reduce the critical current.

Table 1-6. Sextupole, Trim Quad and Corrector Wire Requirements

Requirement	Value: Sextupole and Trim Quad		Value: Corrector	
DIMENSIONAL AND MECHANICAL				
Nominal Filament Diameter	10	μm	10	μm
Nominal Filament Spacing	>1	μm	>1	μm
Nominal Cu to Non-Cu Ratio	(3.0±0.1):1		(2.5±0.1):1	
Number of Filaments	645±10		310±5	
Diameter, bare	0.508±0.003	mm	0.330±0.003	mm
	(0.0200±0.0001	in.)	(0.0130±0.0001	in.)
Twist Direction	Right		Right	
Twist Pitch	0.79±0.08 (2.0±0.2	twists/cm twists/in.)	0.79±0.08 (2.0±0.2	twists/cm twists/in.)
ELECTRICAL				
Minimum I_{crit} @ 2.0 T, 4.2 K	230	A	120	A
Maximum Ratio $I_{crit}(2T)/I_{crit}(5T)$	1.90		1.90	
Wire Maximum R(295 K)	0.112	Ω/m	0.280	Ω/m
Wire Minimum RRR	90		90	