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DATE 7/30/02

MAG

HTS Current Lead Splice Procedure
7-30-02

Purpose: This procedure shall be used by the Cryogenic Feed Box vendor to insure that the splices are prepared in a reproducible, consistent process. This procedure will result in splices that have the required electrical and mechanical properties. In service, the joints will be submersed in liquid helium and will operate at currents up to 7500 A.

Materials:

1. The solder shall be Sn96.5Ag3.5, with a melting point of 221 C. Two types will be required: ribbon manufactured especially for this application (Dwg. No. 5520-MA-369904), and wire (Kester Sn 96 or equivalent).
2. The solder flux shall be chloride-free rosin type (Kester 135 or equivalent).
3. Copper cable, designation LHC-3C-NCU03, to be supplied by LBNL.
4. Superconductor cable, type LHC-3, to be supplied by LBNL.
5. Cartridge heaters (Watlow Firerod 9813 J3A112 L12) Wire with 120 VAC standard power plug.
6. Thermocouples and readout instrumentation
7. Excess solder/flux catch basin.
8. Disposable flux brushes.
9. Isopropyl alcohol
10. Paper wipes
11. Scotchbrite abrasive pads

Parts and Drawings:

1. Solder boxes (Dwg. # 25I6664) shall be OFHC copper.
2. Solder box mounting plates (Dwgs. # 25I6633 & # 25I6703)
3. NEMA G10-CR push blocks (Dwg. # 25I6683)
4. Aluminum push block (Dwg. # 25I6673)
5. NEMA G-10CR clamping plates (Dwg. # 25I6643)

Specifications. The specifications required for this procedure are:

1. MSDS No. 135—for Kester Type 135 rosin soldering flux.
2. ASTM B32-89 (Sn96.5Ag3.5 Solder).
3. CDA 101--oxygen-free copper
4. LHC IR Quadrupole Inner Layer Cable, type LHC-3.

Lead cable description and handling notes:

Four different cables are used in the 7500A lead splices. Two cables are connected to the HTS leads, and are both copper/superconductor composites. The other two cables are connected to the lambda plate; one is a copper/superconductor composite and the other is pure copper. Note: the lambda plug also contains 24 smaller cables that will be treated in a separate procedure.

The pure copper cable is always on the bottom (Dwg. #25I495). Note: although the cables may appear to be rectangular in cross section, they are actually trapezoidal in cross section. Thus, they must be assembled correctly in order to avoid tilting in the soldering fixture. Finally, the cables have limited flexibility in a "hard way" bend, and over-bending will result in decabling.

Splice procedure

1. Install the solder box (DWG # 25I6664), mounting plates (DWG # 25I6633, 25I6703), Nema G10 Push Block (DWG # 25I6683) and clamp Plate (DWG #25I6643) into the LHC IR Feed box. Refer to Photo #1. It should be noted that there are two distinct mounting plates, one eight inches in length and one ten inches in length. Install appropriate mounting plate into appropriate spot in the LHC IR feed box according to the rib spacing. Refer to drawings 25I6854 and 25I6694 for assembly hardware and bill of materials.

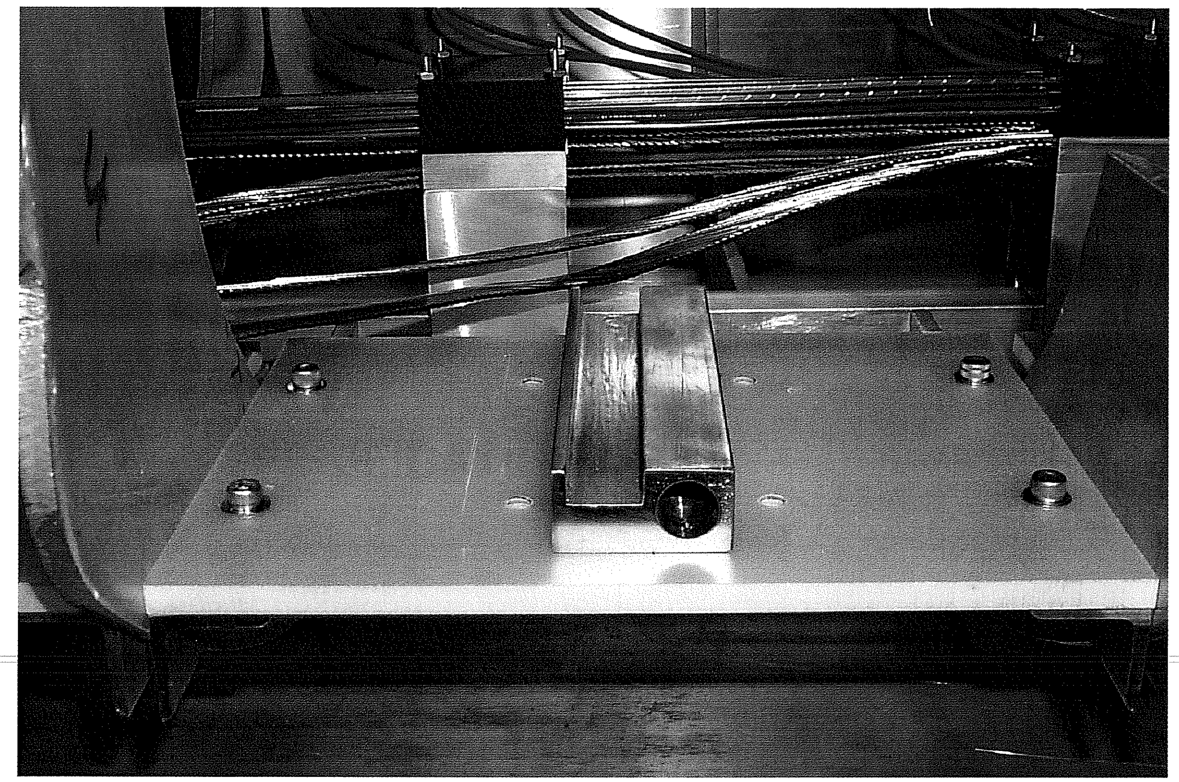

PHOTO #1

2. Determine routing and bend radius for the cable. (Photo #2)
   Note: the cable has a minimum bend radius of six inches; a bend radius less than six inches will cause a separation of the individual cable strands.

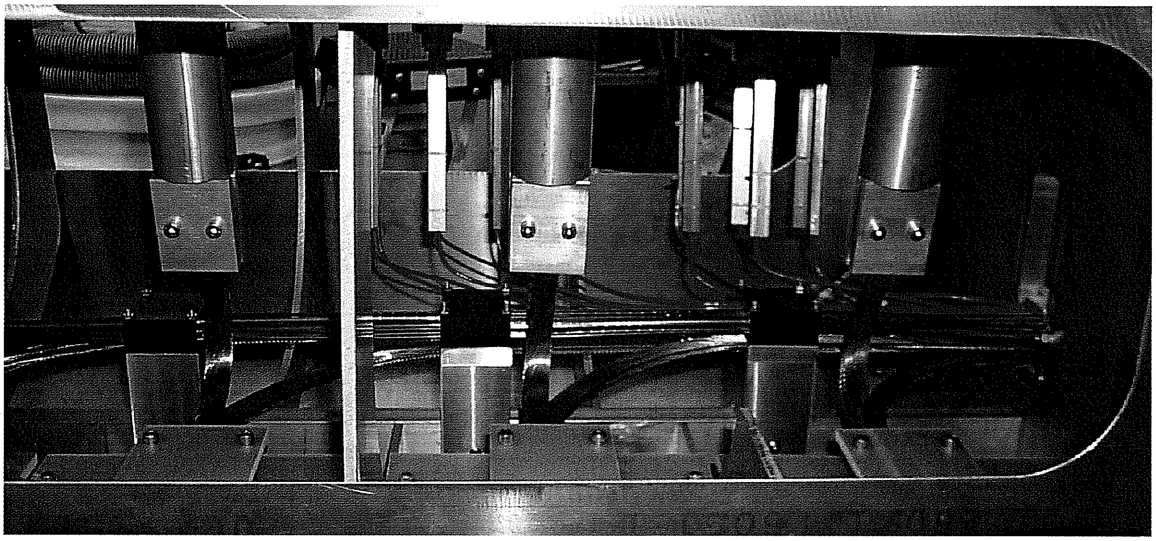

Photo #2

When routing cable and determining bend radius consideration should be made for the routing the cable through the cable looms. Cable looms should be assembled in the LHC IR Feed box prior to the cable routing procedure.

3. Perform a trial layout with the four cables to be used in the splice. Verify that the correct cables are being used. Verify that the cable positions and orientations are correct so that the narrow edges of the keystoned cables will be alternating in the solder splice box. Mark the cables for pre-tinning and cutting to correct length. (Photo #3) Care should be taken not to damage the Kapton insulation surrounding the cable.

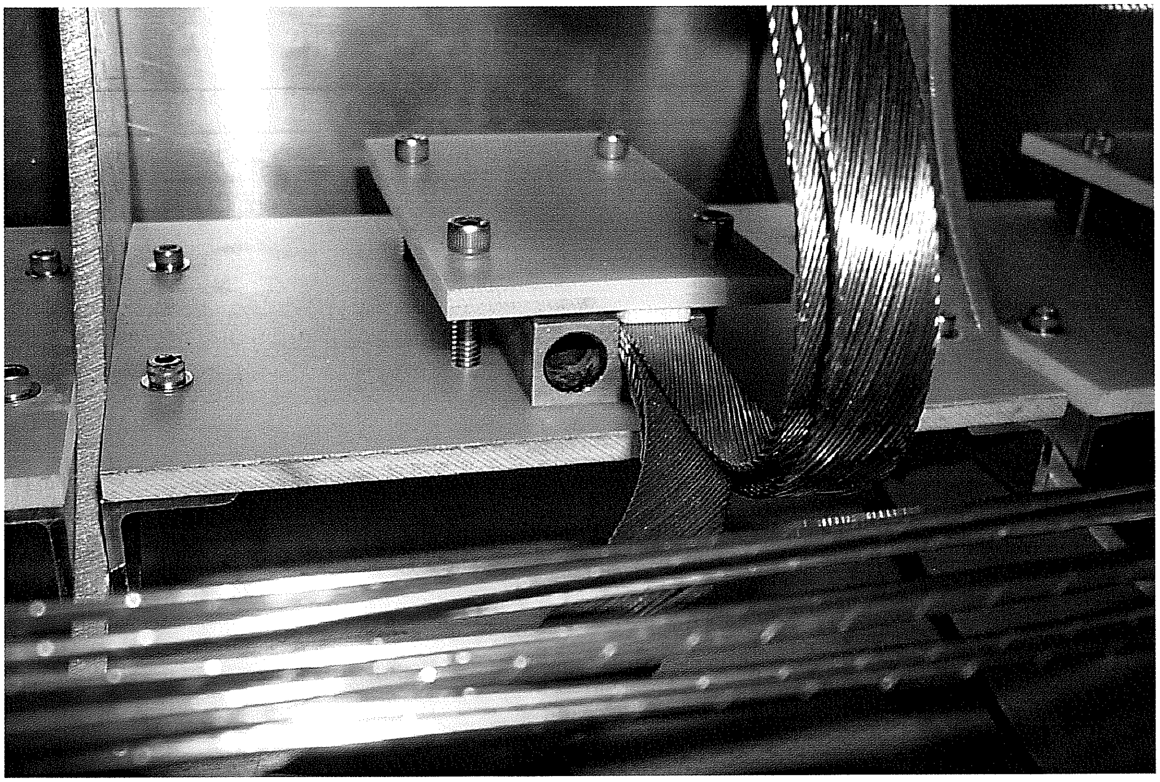

Photo #3

4. Tin the cables. For maximum flexibility, tin the cables only the length of the solder box. Also, the cables from the lambda plug shall be spot tinned at a distance of 100 mm from the end of the splice block, where the voltage tap wires will be mounted.

5. Cut solder ribbon to correct length. Coat cables with flux. Assemble cables in the solder box, with pieces of solder ribbon between each pair of cables, as shown in Photos 4 thru 7.

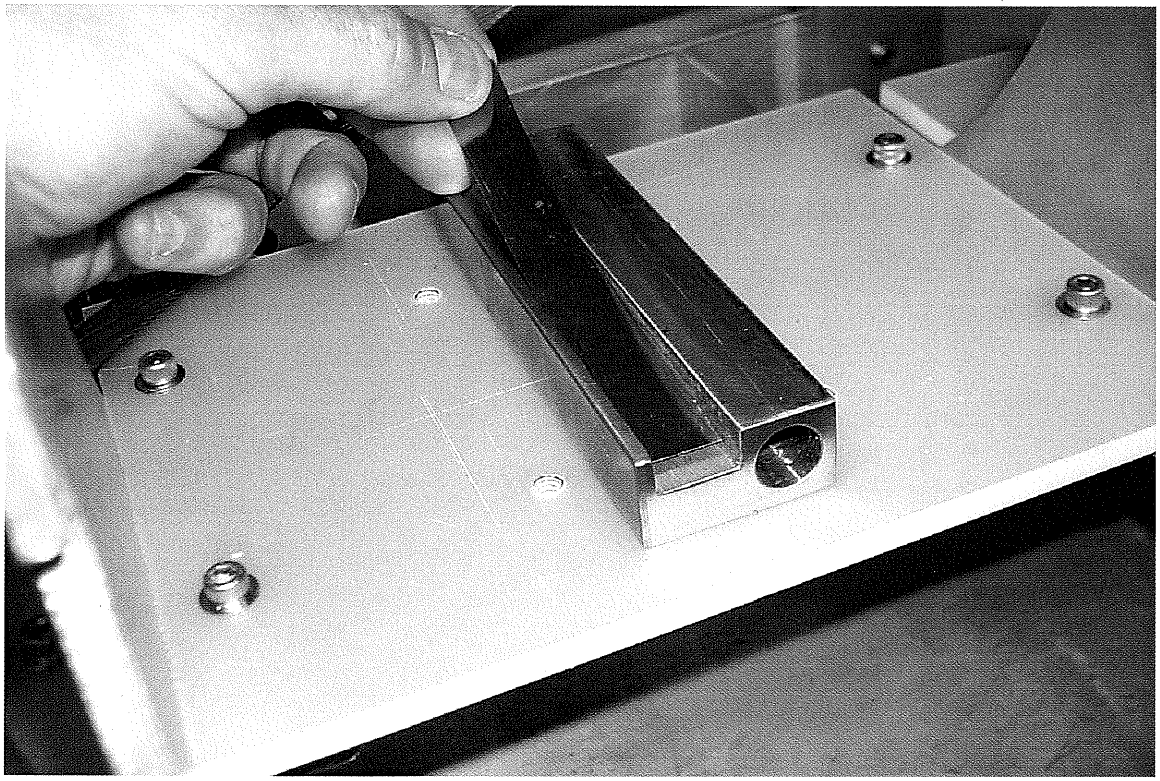

Photo #4

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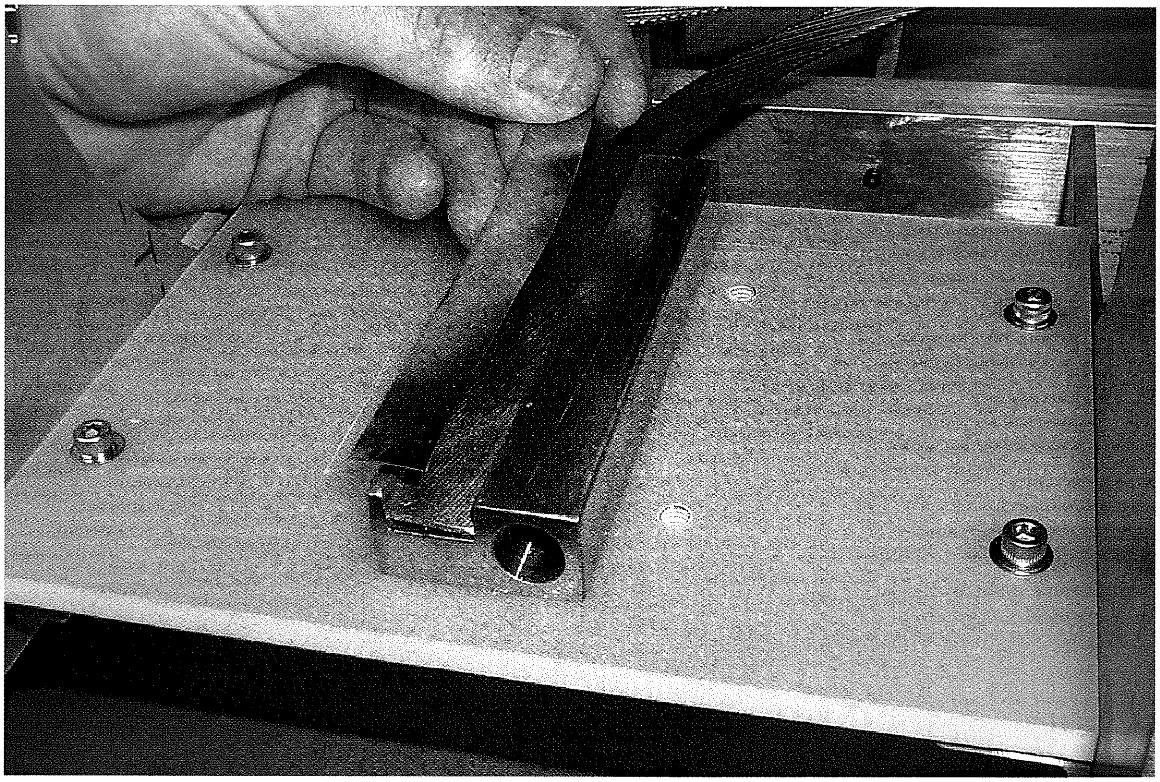

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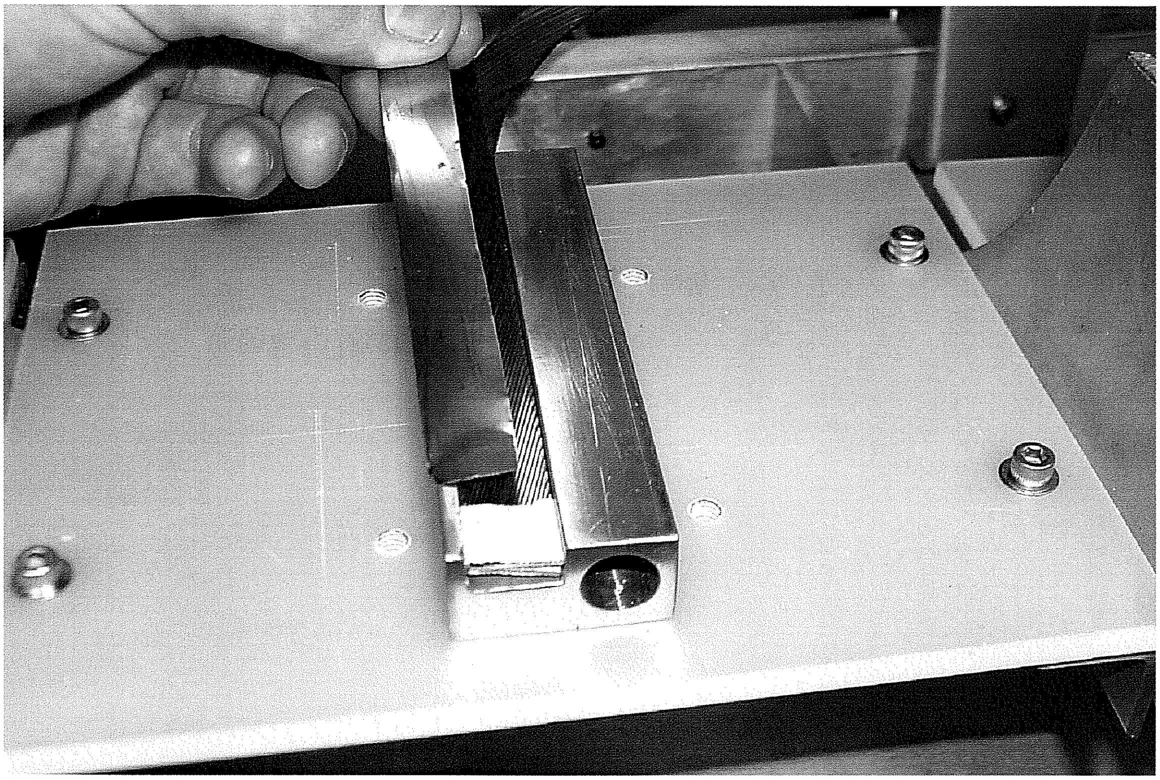

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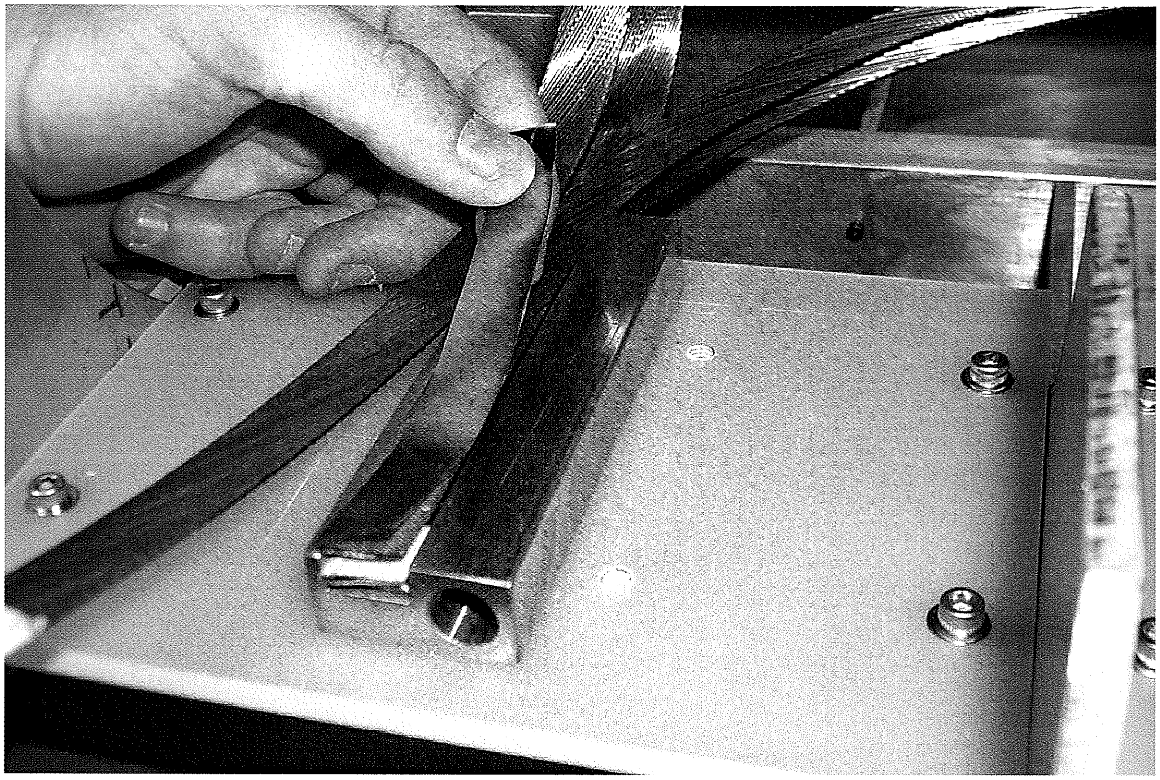


Photo #7

AUTHOR DEPARTMENT DATE
Ron Scanlan, S.Bartlett, J. Swanson, N. Liggins AFRD 7/30/02

6. Place the aluminum push block (Dwg. # 25I6673) into the groove over the top piece of conductor. Hold down and slide the G10-CR clamp plate (Dwg. # 25I6643) onto it. Use the hardware that is specified on the drawing. Start the four bolts and snug down. This will hold tension on the stack while soldering. (Photos #8 & #9)

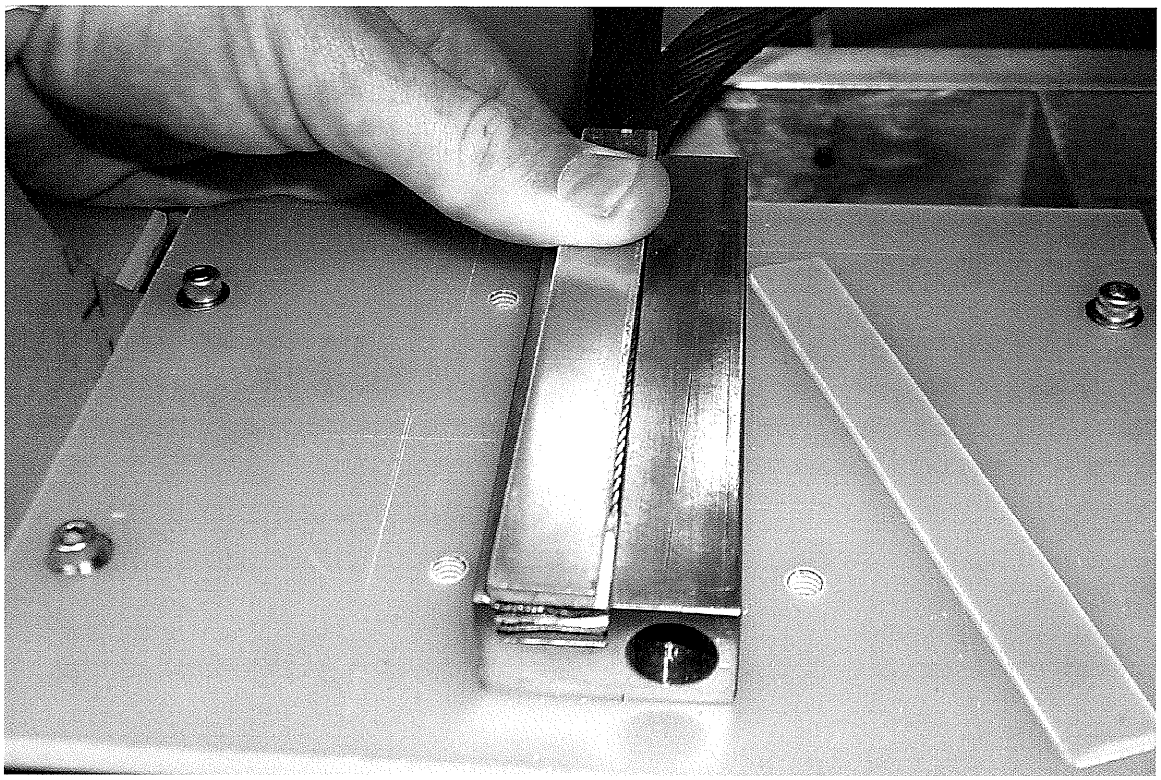


Photo #8

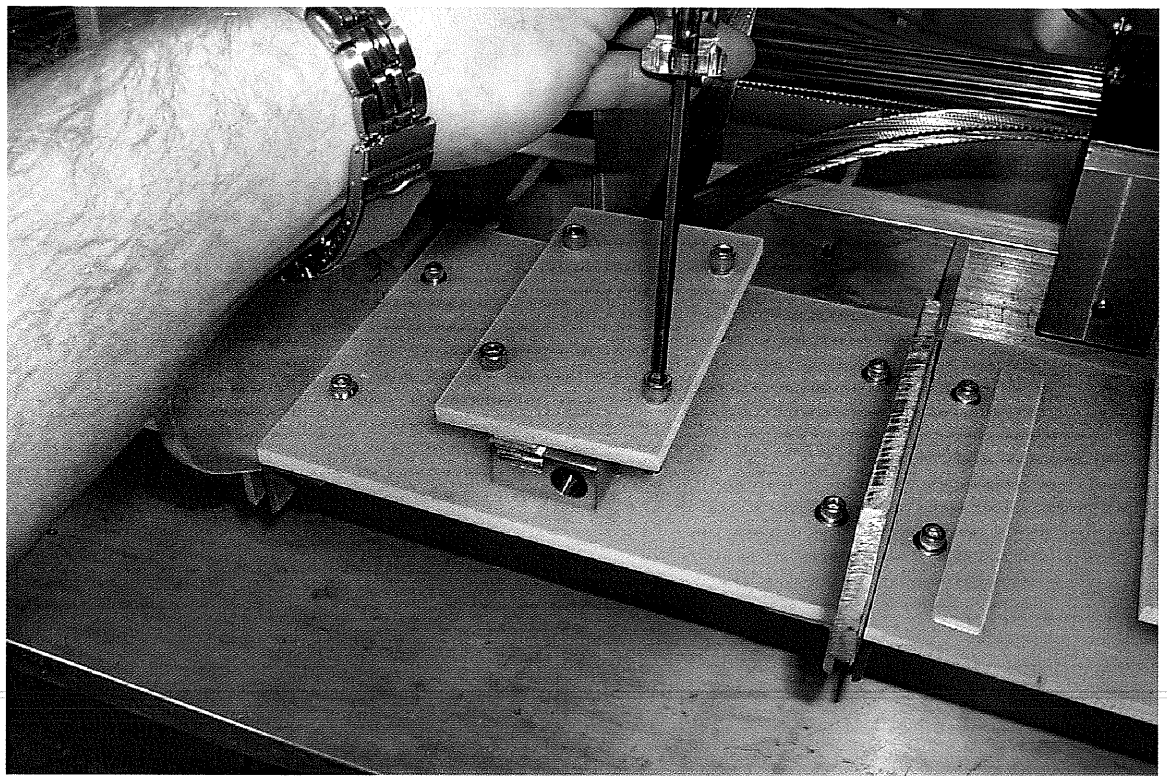


Photo #9

7. Insert cartridge heater into holder. Plug the heaters into 120 VAC source. Use a Variac to control the voltage so as to not exceed 240C. Turn variac on and monitor the progress of heating the cables with the thermocouple in the holder and by observing when the solder melts. Do not allow the temperature to exceed 240 C. Feed in extra solder when solder reaches melting point. Tighten screws on solder fixture to insure that the excess solder is squeezed out of the joint. Keep feeding solder into the joint until the solder has solidified. (Photo #10)

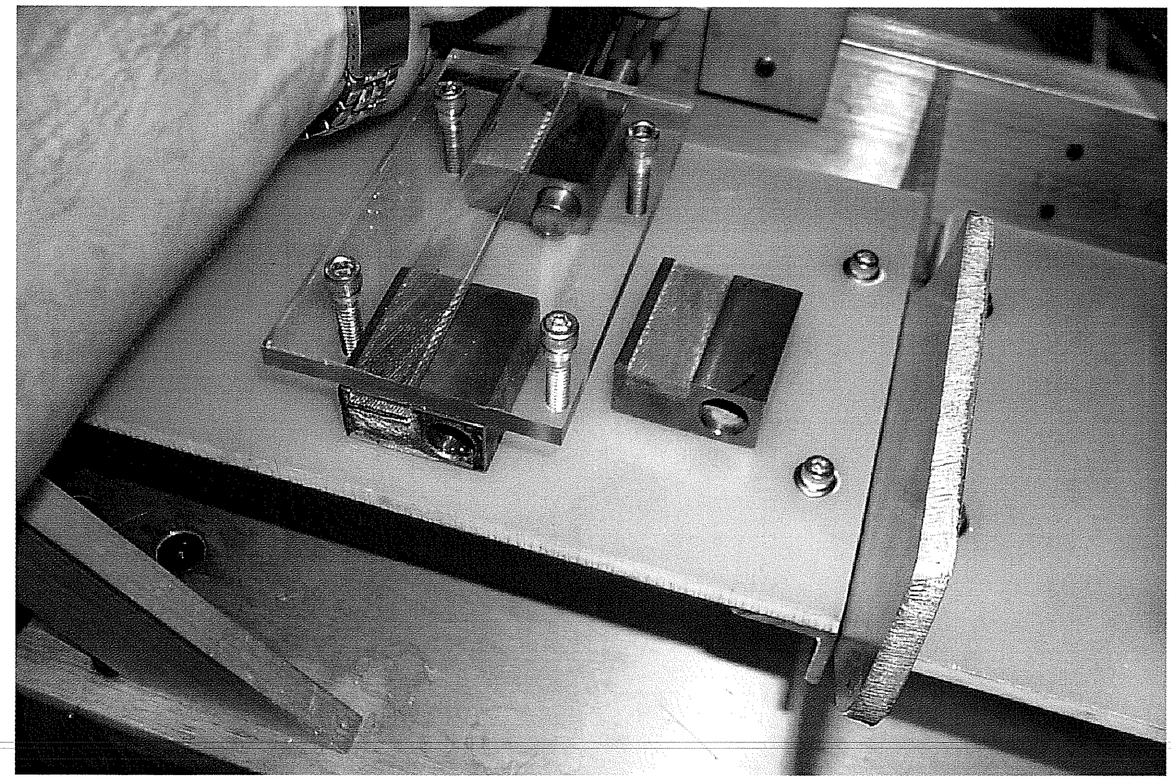
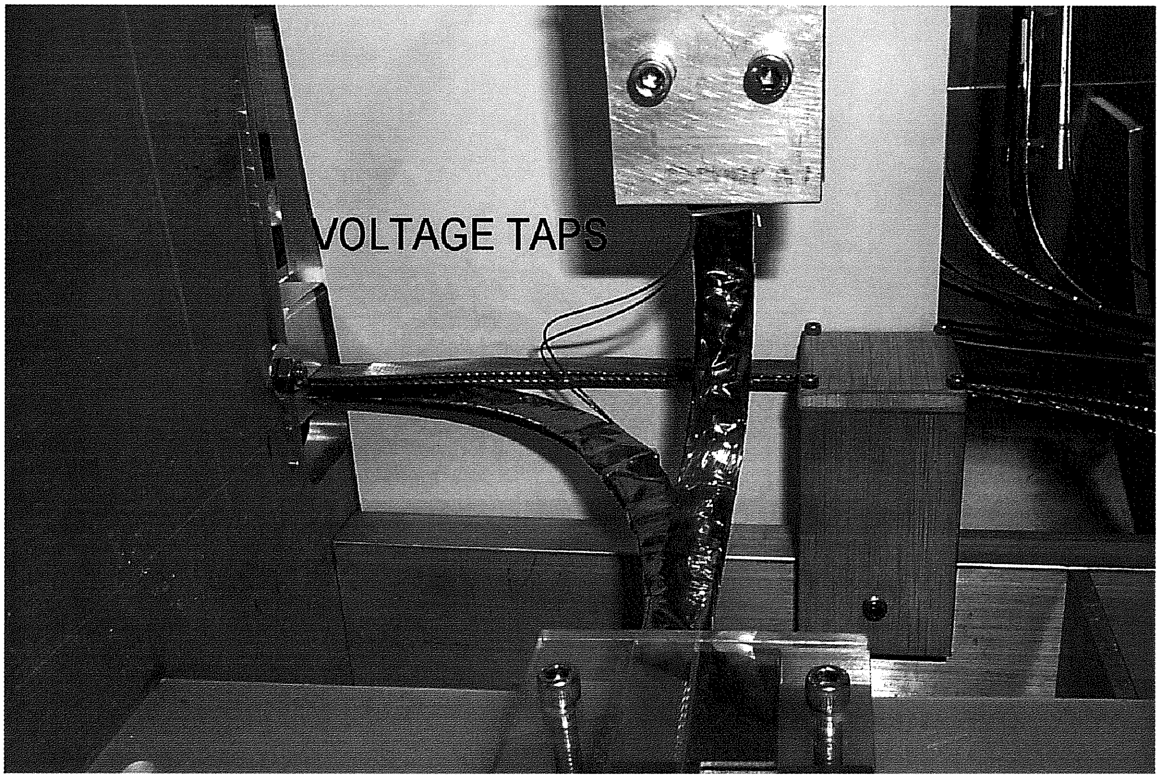


Photo #10

AUTHOR Ron Scanlan, S.Bartlett, J. Swanson, N. Liggins
DEPARTMENT AFRD

8. The cables from the lambda plug should be spot tinned at a distance of 100 mm from the end of the splice block, where the voltage tap wires will be mounted. Strip the voltage tap wires for a distance of 50mm. This end will be wrapped around the large conductor 100 mm from the end of the splice block and twisted around it self. Make this joint using a large soldering iron about 100 mm from the splice block. (Photo#11)



Photo#11

9. After the joint cools, remove the clamping plate and push block.
10. Clean up the joint areas with Scotchbrite and isopropyl alcohol to remove any residual flux and excess solder.
11. Install the G10-CR pusher block (Dwg. # 25I6683) and clamping plate. Tighten up the four screws (Photo #12).

AUTHOR DEPARTMENT DATE
Ron Scanlan, S.Bartlett, J. Swanson, N. Liggins AFRD 7/30/02

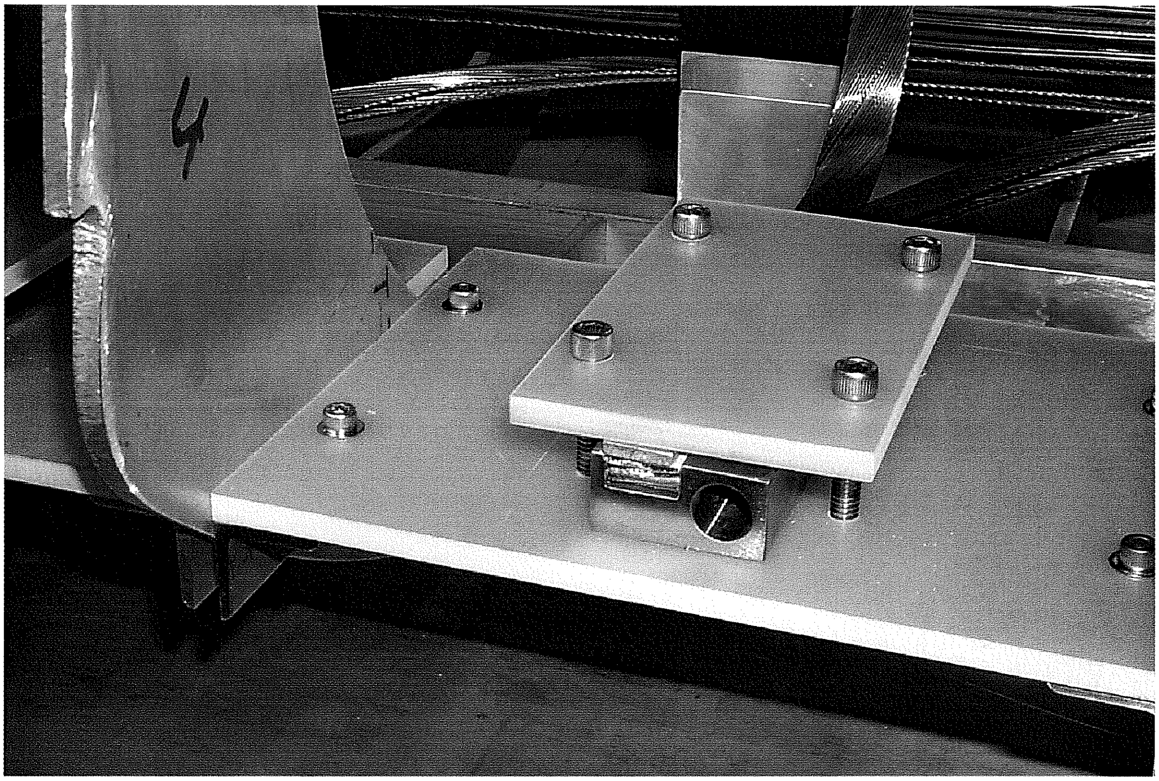


Photo #12

Electrical Performance Test

After the splices are completed and the insulation applied, the high voltage performance shall be verified by performing a voltage stand-off test (referred to as a "hi-pot"test) following the procedure described below. The completed lead system shall be tested to 5000 volts, in a nitrogen atmosphere.

1. SCOPE:
   This procedure describes the general Hi-Potting process to check the integrity of insulation between electrical components.

2. APPLICABLE DOCUMENTS:
   a. LBNL Health and Safety Manual, PUB 3000, Chapter 8, "Electrical Safety".
   b. High Potter technical manual.

3. REQUIREMENTS:
   3.1 Equipment and Materials:
   a. Hypotronics, Model 306B Hy-pot tester or Bertan Associate Inc. Bin Power Module Model 375X high voltage power supply or equivalent.
   b. Grounding strap 1/6" X 7/16" Wide stranded wire or equivalent

   3.2 Safety Precautions:
   a. Follow all applicable safety precautions called for in PUB-3000.
      a1. Pub 3000 rates this operation as a Class 1B hazard (Low), high voltage very low current. The operation will be performed in a Mode 2 classification, (manipulative operations performed on non-energized system. Energized in close proximity to exposed components).
   b. This test is to be conducted only by qualified technicians who have been trained in the proper use of the equipment and who are knowledgeable in the construction of these components.
   c. When testing, insure the area is cordoned off and posted as "DANGER – HIGH VOLTAGE".
   d. Notify the supervisor or responsible person that High-potting will be preformed.
   e. When performing High Pot testing or when around high voltage and handling test leads it is a good practice to keep one hand in your pocket and keep a safe

distance from energized components. Also keep other people away while conducting a high voltage tests.

3.3 PROCEDURE:

3.3.1 Calibration Check:

a. Disconnect all measuring instruments and any source of voltage.

b. Ensure that the Hi-pot meter is off and discharge the D.C. OUT terminal with a ground lead.

c. Use only the SHV test leads provided with the instrument. DO NOT remove the SHV Cable from these instruments. For the Hipotronics tester, plug the BLACK lead to the GROUND terminal and the RED lead to the D.C. OUT terminal. For the Bertan tester, connect the ground strap to the chassis case. Connect a DVM to the voltage monitor and a second DVM to the current monitor. Set the DVM to DC volts and the current monitor to mV. For the Bertan tester, the voltage monitor reads 10 volts = 10KV the current monitor reads 10V = 1mA

d. Connect the GROUND cable or strap to Earth ground.

e. Connect a 20 MΩ resistor across the GROUND and D.C. OUT terminals for either tester.

f. Move the Hipotronics sensitivity knob to the maximum sensitivity. . The Bertan should be set to the 100μA scale

g. Move the range switch to LOW (1-1.2 KV range) or the turn pot to zero voltage in the case of the Bertan.

h. Turn the main power switch on and increase the voltage to 500 Volts. Note the current reading is 25μA. The Bertan should read ¼ of scale on the 100μA setting. If the meter does not read these values the Hi-pot tester is not working correctly. Turn the tester off and reduce the voltage control knob to zero. Inform the Cognizant Supervisor. If the reading is correct raise the voltage towards 1000V and verify the trip point is approximately 50 μA. The Bertan meter will trip at 80% full scale or 80μA. Accordingly, the voltage for the Bertan will trip at approximately 1600 V.

i. Repeat the test if necessary to verify a trip point of less than 50 μA

j. Record the trip point on the Hi-pot record book.

k. Turn the Hi-pot off and discharge it by touching the grounding lead to the D.C. OUT terminal and resistor.

l. Disconnect the resistor.

3.3.2 HI-POT TEST:

a. Ground test point prior to connecting the instruments to discharge any stored energy in the device to be tested. Be aware that high pot test can charge up capacitance in the system. Although the calculated energy in these magnets is less than 5 joules, the stored energy in any system is a concern and the primary source of hazard. If in doubt the capacitance can be measured and should be less than 10μF at 1000V.

b. Connect the (+) SHV lead to the magnet or magnet component.

c. Connect the ground strap to EARTH ground, to the ground potential of the respective component, and to the chassis case or ground terminal.

d. Move the sensitivity knob to the maximum setting. For the Bertan the sensitivity setting is 1μA.

e. Move the Voltage control setting to low and the control knob to the minimum position.

f. Move the current meter setting to X100 for the Hipotronics.

g. Turn the High Pot tester power switch on. Turn the VOLTAGE control knob very slowly to raise the voltage until 1000 V (1KV) has been reached. Switch to the high setting and continue to increase the voltage until the specified voltage is reached. The reading should be less than 10μA.

h. Record the reading, inform the cognizant supervisor of any reading is greater than 10 μA.

m. A fault in the insulation or in the test connection will cause the meter to trip off. Turn the Hi-pot tester power switch off, turn the voltage control to the minimum position, and then discharge the component and tester by touching the Ground cable to the positive terminal connection. You can now disconnect the lead.

n. DO NOT REPEAT THIS TEST UNNECESSARILY AS IT MAY CAUSE A CARBON TRACK OR ARC POINT DAMAGE TO A COMPONENT.

LHC IR QUAD Magnet Inner and Outer Cable Manufacturing Specification

1 SCOPE

This specification establishes the requirements for the fabrication, inspection, test, identification and delivery of superconducting NbTi cables for Fermilab LHC IR quadrupole magnets.

1.1 Cable definition

The cable is composed of superconducting wires which are twisted around a hollow core and pressed into a keystoned shape. Two types of cable are required, one for the inner coils and one for the outer coils.

2 REFERENCE DOCUMENTS

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

SSC-M35-000014	NbTi Superconducting Wire for SSC Dipole Magnets (1.3 grade inner)
SSC-MAG-M-4146	NbTi Superconducting Wire for SSC Dipole Magnets (Outer)
SSC-M35-000015	NbTi Superconducting Cable for SSC Dipole Magnets (1.3 grade inner)
SSC-MAG-M-4148	NbTi Superconducting Cable for SSC Dipole Magnets (Outer)
SSC-M35-000110	Packaging and shipping of superconducting cable
SSC-MAG-402	Appendix A, B

3 REQUIREMENTS

3.1 Wire receiving and handling

The wire shall be inspected and tested upon receipt to check that it complies with the following requirements:

3.1.1 Wire supplier responsibility

Table 1 summarizes the strand parameters.

1. Critical current. The conductor for the inner layer shall have a minimum critical current of 378 A, measured at 7 T and 4.22 K; the conductor for the outer layer shall have a minimum critical current of 185 A, measured at 7T and 4.22 K. The critical current will be determined according to a criterion of $\rho=10^{-14}$ Ωm, based on the wire cross section area and with the applied magnetic field perpendicular to the wire axis.
2. Copper to non-copper ratio. The copper to non-copper ratio shall be (1.3±0.1):1 for the inner layer conductor and (1.8±0.1):1 for the outer layer conductor.
3. Wire diameter. The conductor for the inner layer shall have a diameter of 0.808±0.0025 mm. The conductor for the outer layer shall have a diameter of 0.6505±0.0025 mm. The conductor dimension shall be established by continuous wire gauging, under an applied tension of 2.7Kg.
4. Surface condition. The wire surface shall be free of all surface defects, slivers, folds, laminations, dirt, copper fines, or inclusions. No NbTi filaments shall be visible at 10x under a lighting level of at least 1076 lux.
5. Wire twist pitch. The conductor for the HGQ cable shall be twisted so that the filaments follow the opposite rotation as the cable lay direction. The inner layer wire twist pitch at final size shall be (13 ±1.5) mm. The outer layer wire twist pitch at final size shall be (13 ±1.5) mm.
6. RRR. The conductors for inner and outer cable shall have a minimum RRR value of 70 after annealing. The test procedure of RRR is described in Appendix III.

Table 1. Strand mechanical and electrical specifications

Parameter	Unit	Inner cable		Outer cable	
		Value	Tolerance	Value	Tolerance
Diameter	mm	0.808	± 0.0025	0.6505	± 0.0025
Cu/SC ratio		1.3 : 1	± 0.1	1.8 : 1	± 0.1
Surface coating		None	-	None	-
Anneal		None	-	None	-
Minimum critical current	A	378	-	185	-
Minimum RRR		70		70	
Twist direction		Left		Right	
Twist pitch	mm	13	± 1.5	13	± 1.5

3.1.2 Cable vendor responsibility

1. Mechanical properties. The wire shall survive a sharp bend test (Appendix IV).
2. The wire awaiting cable fabrication shall be identified, protected, and handled in a manner to prevent degradation or damage.

3.2 Technical requirements for cable

Figure 1 shows the cable size parameters and Table 2 summarizes the cable mechanical and electrical parameters.

3.2.1 Mechanical properties

1. Cable size, strand number, cable transposition pitch, lay direction, surface coating, and strand anneal are specified in drawing numbers MA-369202 and MA-344389A for the inner and outer cable, respectively. The method for determining that the cable dimensions comply with the requirements are described in Appendix A of document SSC-MAG-M-402 (Test Method 402-1 - Cable Thickness. Width and Keystone Angle). The cable mid-thickness is measured under a pressure of 5 ksi (34.47 MPa).

   If the cable has a "right lay" pitch the strands should be spiraled in the same direction as right handed screw thread. The converse is true for a left lay direction. Figure 1 shows the cable size parameters and Table 2 lists the specifications.
2. Collapse tension. The bare cable shall withstand a tension of 50 Kg without loss of mechanical integrity.
3. Residual twist. The residual twist shall be in the following range: between 0° and 90° in the direction of the cable lay. The twist is measured by suspending a 11.34 Kg (25 lb.) weight from a 1m length of cable.

3.2.2 Electrical properties

Critical current at 7T, 4.22K must be higher than 14.0 kA and 8.5 kA for inner and outer cables, respectively. The cable electrical properties are also described in Table 2. The methods used to measure the electrical properties are described in Appendix B of document SSC-MAG-M-402.

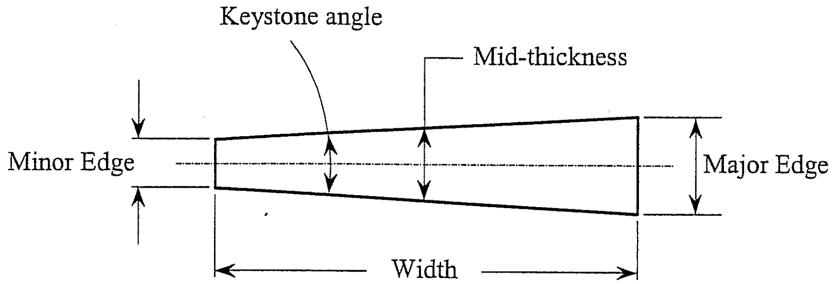


Figure 1 The cable size parameters.

Table 2. Cable mechanical and electrical specifications

Parameter	Unit	Inner cable		Outer cable	
		Value	Tolerance	Value	Tolerance
Number of strands		37	-	46	-
Cable width	mm	15.40	± 0.025	15.40	± 0.025
Minor edge	mm	1.320		1.051	
Cable Mid-thickness	mm	1.465	± 0.006	1.146	± 0.006
Major edge	mm	1.610		1.241	
Keystone angle	degree	1.079	± 0.05	0.707	± 0.05
Transposition length	mm	114	± 5	102	± 5
Lay direction		Right	-	Left	-
Minimum critical current	kA	14.0	-	8.5	-
Minimum unit length	m	180	-	200	-
Minimum collapse tension	Kg	50	-	50	-
Residual twist	degree	0 ~ 90		0 ~ 90	
Minimum bending radius	mm	7		15	

3.3 Processing

3.3.1 Identification

Each piece of wire (strand) and cable in the cable fabrication process shall be identified by a unique code number. Wire identification shall be traceable to the final cable serial number. All cable fabrication material, processing, inspection, tests, and delivery records shall be retrievable to either wire or cable code numbers.

3.3.2 Strand Map

The cable manufacturer shall supply a strand map giving the serial numbers of the strands used in the cable manufacturing.

3.3.3 Cable lengths

The unit length of cable is 180 m for the inner layer cable and 200 m for the outer layer cable. The cable shall be delivered in multiples of the unit length. Fermilab requires at least 95 unit lengths of inner cable and 95 unit lengths of outer cable.

3.3.4 Strand Welds

No cold welds are allowed in any unit length of cable. Cold welds used in setup must be clearly marked, and position of the cold welds must be listed in the production report. These cold welds must be removed before the cable is shipped to FNAL.

3.3.5 Cable surface condition

The cable surface must be thoroughly clean and free from oil, metallic particles or residue. Cleaning solvents shall be in accordance with cable cleaning specification 5525-ES-369499. The cable must be free of roughness, sharp edges or burrs.

3.3.6 Crossover or broken strands

There can be no crossovers of strands or broken strands in the cable

4 PREPARATION FOR DELIVERY

4.1 Reels/Spools

The cable must be spooled with a radius larger than or equal to 0.3 m. The spools must be constructed to prevent damage to the cable during spooling and unspooling. The spools shall be boxed to prevent damage in shipment. They should be stacked and shipped with the spool flanges maintained in a vertical orientation (axis horizontal) in order to prevent the cable from settling on the spool.

4.2 Spooling requirements

The cable must be wound on the spool so that there are no crossovers of the cable layers. Filler cord shall be used at the edges of the cable layers as required so that the cable will be adequately supported over the whole wide face and will lie flat. Only one continuous length of cable is placed on each spool.

The cable will be wound onto a spool in the following manner: As an observer is looking at the collecting spool, if the spool is rotating clockwise, then the thick edge of the cable should be facing the observer.

5 QUALITY ASSURANCE AND MANUFACTURING PLAN

5.1 Quality Plan

The cable manufacturer is responsible for performing the inspections and the tests defined in Table 3 and the preparation and maintenance of resultant data. BNL will perform the critical current and RRR measurements on samples supplied by the cable vendor from the beginning and end of each cable length upon completion.

5.2 Certificate of compliance

The cable manufacture shall provide a written statement certifying compliance with the requirements of this specification with each product shipment, together with a completed copy of test result data. The result data is to be provided in an electronic form (ASCII file) also.

This documentation shall be provided to Fermilab after the completion of all tests, measurements, and inspections, and Fermilab shall provide in writing an acceptance certificate. No cable shall be delivered prior to the receipt of this acceptance.

5.2.1 Nonconforming material

Finished cable failing to meet the requirements of table 2 shall be identified by condition and segregated from conforming material. Material shall remain on hold pending buyer notification and disposition.

5.3 Shipping

The cable spool shall be shipped as a palletized unit.

1. Place the spool on a pallet custom made to the size of the spool, with the spool flanges maintained in a vertical orientation (axis horizontal) in order to prevent the cable from settling on the spool. (Custom pallets are reusable.)
2. Attach the spool to the pallet through the horizontal axis of the spool with banding material (palletized unit).
3. Cover the entire package with a 5/8 inch plywood crate banded to the pallet holding the plywood cover in place.

5.4 Marking/Identification Requirement

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

LHC IR QUAD superconducting cable	
Type (Inner or Outer)	I or O
Buyer P.O. No.	______
Reel ID.	L-3-A-Nxxxx
Drawing No.	______
Length (m)	______
Weight (kg)	______
Strand Map No.	______
Date of Manufacture	______
Name of Manufacturer	______

Table 3. Finished cable acceptance inspection/test

Characteristic	Requirement value	Test Specimen sample [1]	Frequency	Test method [1]
Cable mid-thickness	See 3.2.1	TM-402-1	Each 30 m	TM-402-1
Cable width	See 3.2.1	TM-402-1	Each 30 m	TM-402-1
Cable keystone angle	See 3.2.1	TM-402-1	Each 30 m	TM-402-1
Cable lay direction	See 3.2.1	TM-402-3	Beginning and end of each cable length	TM-402-3
Cable lay pitch	See 3.2.1	TM-402-2	Beginning and end of each cable length	TM-402-2
Strand twist pitch	See 3.1.1	Etched 10cm piece	Beginning and end of each cable length	TM-402-4
Bend strength	No cable damage	TM-402-5	Beginning and end of each cable length	TM-402-5
Surface condition	See 3.2.3	100%	100%	
Strand integrity	No broken strands	100%	100%	Visual test
Cable critical current	Table 2		Beginning and end of each cable length	Appendix I
Cable RRR	Table 2		Beginning and end of each cable length	Appendix II

1. Test method descriptions are included in Appendix A of SSC-MAG-M-402.
2. The cable measuring machine shall be used as described in TM-402-1 for the noted tests.

Appendix I Cable Critical Current Determination

I.1 Introduction

The sections below describe the test method used at BNL to determine transport critical currents of meter long cable samples. The measurement of critical currents of order 10^4 A is more difficult than the corresponding measurement for a wire carrying several hundred amps for a number of reasons. Large power supplies are required and sensitive voltage measurements must be made in the presence of much noise. Forces on the samples are large and care is required to restrain mechanical motion. Finally, self-field effects are large and must be carefully corrected. This section describes the methods and procedures that have been developed at BNL over a number of years. These procedures have proven suitable for production testing.

The critical current of a cable, I_c, is somewhat less than the sum of the individual wire values as there is invariably some degradation during the fabrication of the cable. This is expressed as follows:

$$D = 1 - \left(\frac{I_c}{\sum I_{cw}} \right)$$

where ΣI_{cw} = sum of the Ic's of the wires in the cable. An allowance for degradation, in modern practice, is $D < 0.05$ (=5%).

The critical current is a function of temperature, T, and magnetic field, B. It is generally necessary to convert (or "correct") short sample test results obtained at particular values of T and B, to values corresponding to a standard temperature and field. The steps in this conversion are as follows:

5.1 (

a) Obtain raw data for several applied fields: I_{ct}, critical current at bath temperature, T, and applied field, B_a. For LHC quadrupole cable, the applied fields are 6.7, 7.0, 7.3 T for inner cables, and 5.6, 6.3, 7.0 T for outer cable.

b) Calculate the peak field, B: the sum of the applied field and the self-field, due to the measurement current.

c) Convert I_{ct} at field B to I_c, the value corresponding to reference temperature T_{ref}.

d) Plot I_c vs. B and calculate I_c at the reference field from a linear fit to the data.

The calculations used in the above steps are described in detail below. The I_c vs. B short sample curve may be combined with the load line of the magnet to obtain a prediction of its expected performance.

I.2 Definition of Critical Current

Accelerator magnet cables are designed to carry currents of 1-15 kA in fields of order 6-7 T, at 4.2 K. The voltage drop under these conditions is not zero; typically it is a few μvolts per meter. The variation of voltage with current can be measured in a range corresponding to about 0.5 μV/m to 50 μV/m. Smaller voltages are difficult to measure. At the high end, the V-I curve is unstable and an irreversible quench occurs. For currents less than the quench current, the V-I curve is reversible. The critical current is a property of the reversible portion of the V-I curve. It is defined as that current for which

$$V/I = \frac{10^{-14}}{\left(\frac{N\pi d^2}{4} \right)}$$

where V = voltage drop per m, I = current in amps N = no. of wires in cable d = wire diameter in m. The shape of the V-I curve is of the form $V = \text{constant} \times I^{n+1}$. (Note that n is defined from the equation $\rho = \text{constant} \times I^{n}$). The quantity n is routinely measured as required by the specifications. Large n-values are indicative of uniform filaments. The n-value is, therefore, a useful diagnostic for monolithic conductors and individual wires, although less so for cables. Usually low n-values is associated with conductor damage due to cabling, or it may be due to current-transfer effects. It is sometimes required that n exceed a specified value for some types of conductor.

The quench current is dependent on T and B in a somewhat similar way as the critical current. Unlike the critical current, however, it is also dependent on several external factors: insulation, ramp rate, mechanical security. These affect the characteristic feature of quench current behavior, viz., training. This is the increase in quench current upon successive applications of current until, except in pathological cases, a limiting or plateau value is reached. This value is referred to as I_q. Temperature and field corrections are not generally made for I_q.

The number of training quenches is minimized in short sample testing by using bare cable samples and by strong mechanical clamping as discussed below. I_q is generally greater than I_{ct} and, as it provides a measure of the ultimate current carrying capability of the cable, it is routinely recorded. If I_q is less than I_{ct}, the latter may be determined by extrapolation provided there is enough of the V-I curve to permit this. However, in this event I_{ct} is of academic interest only as it cannot be attained in practice.

I.3 Sample Mounting

The samples are mounted in a compression fixture, which is illustrated in Figure I.1. The usual test arrangement involves four bare cable samples. As these are keystoned, (i.e., they are trapezoidal in cross-section), care is taken to alternate thick and thin edges so that pairs of conductors present parallel surfaces to the clamping faces. As indicated in Figure I.1 there are a series of separators: 0.76 mm. thick G-10 strips which carry electrical instrumentation described below, and 0.25 mm. thick Mylar strips which insulate adjacent samples of the upper and lower cable pairs.

Compression is applied by tightening 9.53 mm (3/8 in.) bolts. These run along each side at 38 mm intervals. A torque of 53 N-m (240 inch-pounds) is used to tighten the bolts. This produces a clamping pressure of 54± 7 MPa for the 15 mm wide HGQ cables at room temperature. The pressure has been found to increase slightly at low temperature. With this method training behavior is limited to a few quenches.

The sample compression fixture is supported together with the sample leads from a room temperature flange, which may be rotated. The standard configuration for quality control testing is the perpendicular one, i.e., the applied dipole field is perpendicular to the sample faces. In this configuration, a strong twist about a vertical axis is generated by a bifilar sample for currents above a few kilo-amps in fields above several Tesla. Rotation of the sample fixture relative to the magnet is prevented by means of a locating key on the fixture and a slotted plate at the bottom of the magnet.

Figure I.2 shows schematically how the cables are connected to each other and to the gas cooled leads. The connections are made using ordinary soft solder over a 15 cm. length. A typical joint resistance is about 10^{-9} ohm. The samples are excited in pairs, either A-B, or C-D.

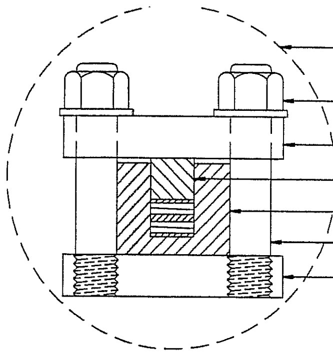


Figure I.1 Mechanical assembly of 2 pairs of cable.

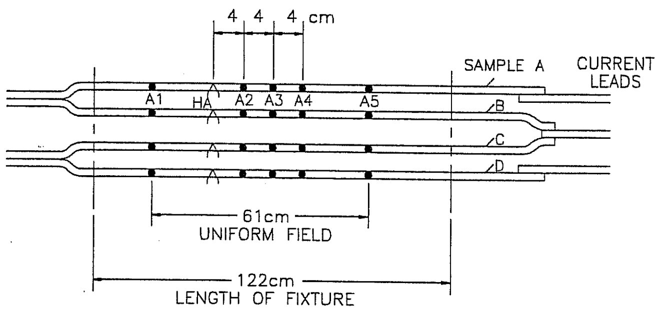


Figure I.2 Electrical Wiring Schematic.

I.4 Electrical Instrumentation

Primary instrumentation consists of the following:

- Five voltage taps and thin foil heater element for each sample.These are contained on the G-10 strips shown in Figure I.2. The voltage taps work by the pressure contact of a copper wire across the width of the sample; the leads run out through a fine groove in the G-10. The heater element is a strip of stainless steel foil, 0.013 mm. thick x 3 mm. x 6 mm, which is located in a shallow well formed in the G-10 strip.
- Hazemeyer DCCT secondary current standard.
- Digital voltmeters, 6-1/2 digit, 0.1 μV sensitivity.
- Nicolet 12 bit, 4 channel digital oscilloscope.
- Two calibrated carbon resistor thermometers, located at each end of the magnet.
- Isolation preamplifiers, 1 mV noise level.

Secondary instrumentation consists of the following:

- Quench current protection circuits for the magnet, the gas-cooled leads, and the samples.
- DC power supplies for persistent switch, and sample heater element.

- Pulse power supply for sample heater element.

I.5 Measurement Procedure

The cable samples are energized in pairs, either A-B or C-D in Figure I.2 and the V-I curves are determined simultaneously for each member of the bifilar pair. In the event that one member has a low I_q its partner may not be measurable in the set-up. The latter must be tested at another time with a partner having a comparable I_q - another piece of the same cable, for example. In situations like the preceding, a minimum of two and perhaps three of the cable samples can be measured. In quality control tests of production cables, the match between samples is close enough that I_c's can usually be determined for all four samples. In the rest of this section we shall describe the procedure for testing one cable only, it being understood that a pair of samples, or all four, are under simultaneous test.

The measurements are made with the helium bath level above the upper sample and well above the top of the dipole magnet. The magnet field is set to a desired value and locked in with the persistent switch. The standard arrangement is such that the field is oriented perpendicular to the cable face.

The relative direction of the current flow and of the magnet field is very important for reasons which will be discussed below. Therefore, the polarity of the power supply connections is carefully checked. Before the V-I curve is measured the sample is trained. This is done by ramping the current until a quench occurs. For relatively high Cu/SC ratio cables, as in the RHIC design, one quench is usually sufficient to reach the plateau value of I_q.

In the past a point-by-point method was employed to measure the V-I curve. For LHC testing voltage-current readings are taken with a current ramp of ~200A/s. The most important feature of this method is that a very high degree of filtering of noise voltage can be achieved by the following technique. The noise is mostly in the form of harmonics of the line frequency. By integrating the voltage signal for an integer number of cycles, this harmonic noise is filtered to a very low value. In practice, the integration is over 10 cycles, and AC peak-to-peak voltages of order 10^{-3} volts are reduced to an effective uncertainty in any DC reading of 10^{-7} volts. I_q is determined while ramping by means of a peak-reading DVM. I_q is determined by one sample of the pair being measured; this value is a lower limit of I_q for the other sample. By observing the quench on a digital oscilloscope one can determine in which sample the quench originates. It is usually the one with the lower I_c value.

On-line the V-I data are converted to log ρ - log I data and fitted by a straight line. This gives the 10^{-14} ohm · m current and the n-value (the slope of the log-log plot). However off-line a separate analytical technique is used for calculating I_{ct} and n-value. Details of this evaluation technique is given in the publication referenced below[1]. The results of this analysis are reported: B_a, T, I_{ct} I_q, n, where B_a is the applied field, and I_q is the quench current or a lower limit of it. This procedure is repeated for each of the four cables at several fields in the vicinity of the specification field.

I.6 Temperature Calculation

Calculations of the critical currents at temperatures other than that at which I_c is measured are made using the same procedure as that for wires. The specification temperature is usually 4.222 K, that of boiling helium at standard atmospheric pressure. The bath temperature is recorded with the aid of cryogenic thermometry with a precision of ± 0.002K (2 mK). A "linear T" type of correction is applied for temperatures different from 4.222 K:

[1] " Testing and Evaluation of superconducting cables for the LHC", R. Thomas et. al.. Proc. Of the 1999 Particle Accel. Conf., New York, 1999, p.3188

$$\frac{I_c}{I_{ct}} = \frac{T - 4.222}{T_c - T_{bath}}$$

$$T_c(B) = 9.2\left[1 - \frac{B}{14.5}\right]^{0.59}$$

where $T_c(B)$ is the transition temperature at the specified magnetic field. I_{ct} is the current measured at temperature T, and I_c is the critical current at the specification temperature. The only difference being that the field B is not just the applied field but that which takes into account the field produced by the cables as explained below.

I.7 Magnetic Field Correction[2]

The magnetic field is the sum of the applied field produced by the dipole magnet and the self-field produced by the measuring current. The latter produces a substantial correction. However, since the self-field is spatially non-uniform and depends upon the geometrical details of the bifilar sample, its effect on the V-I curve is difficult to calculate precisely. Experience has shown that the following assumptions give results that are self-consistent for a wide variety of geometry and which give reliable predictions of magnet behavior.

a) The critical current of the sample is determined by the peak magnetic field. This depends, of course, on the orientation of the applied field and the direction of the sample current. This important point will be discussed further in the next section.

b) The sample current is distributed uniformly over, and normal to, the area of the trapezoid that encloses the cable cross-section.

c) The geometry is accurately reproducible; this is a matter of care in assembly, as discussed above.

With the dipole field perpendicular to the wide face of the sample, the peak field occurs at a point on the surface of the sample where the self-field and the applied field are very nearly parallel; that is, they are simply additive. For the standard test configuration, therefore, the self-field correction can be written:

$$B = B_{peak} = B_a + c \times I_{ct}$$

where B_a = dipole field and c = geometric constant. Below is given the value of c for HGQ cable, for B_a perpendicular to the sample, and for the standard BNL test geometry in which the bifilar samples are separated by 0.25 mm

Self-field constant, c, T/KA, for HGQ Cable1: 0.02480

Self-field constant, c, T/KA, for HGQ Cable2: 0.02530

I.8 Critical Current of the Thin Edge:

The thin edge of a keystone-shaped cable is of special interest for two reasons. First, it forms the inner surface of a dipole (or quadrupole) magnet coil, and the maximum value of the field occurs there. Second, this part of the cable experiences the most deformation during fabrication, and possibly the most degradation. The bifilar sample test arrangement with applied field perpendicular has the characteristic feature that the peak fields occur at diagonally opposite points, at the two thin edges (c.f. Figure I.3). Experience has shown that when the current is reversed, so that the peak field points are along the thicker edges, a higher critical current is measured (even though the calculated peak field is slightly higher in this case). This is due to the

[2] " The effect of self field on the critical current determination of multifilamentary superconductors", M.Garber et.al., IEEE Trans. on Magnetics, Vol25, p1940 (1989)

smaller degree of degradation along this edge. In practice, the quality control test determines the critical current for the thin edge; i.e. the field and current direction are oriented as in Figure I.3.

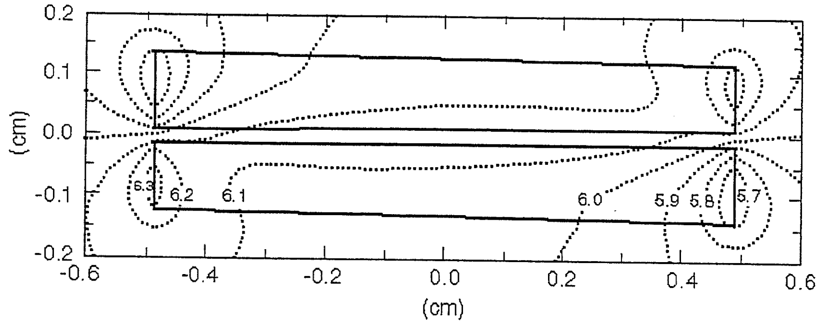


Figure I.3 Contours of constant field magnitude for perpendicular applied field of 6T and current of 10kA. The peak field of 6.4T occurs at the thin edge of the cable.

I.9 Data Averaging Using I-B Graph

The critical currents are plotted on a graph of I vs. B and I_c is obtained from an interpolation to the specification field.

The degradation of the cable, as mentioned before, is $D = 1 - (I_c/\Sigma I_{cw})$. In practice, a few wires may be measured and ΣI_{cw} estimated from this sample, but in cases where questions arise as to whether D meets a specification, it is necessary to determine I_{cw} for all the wires in the Cable Map.

We have ignored the fact that the critical current of a wire is also subject to a self-field effect. However, it has become general practice not to take account of this correction, notably in discussions of J_c in the literature. For cables it is not acceptable to ignore self-field corrections for the reasons given previously: sensitivity of measurements to sample configuration and comparison of data with magnet performance. As a result of this convention, the specified degradation is lower than the true degradation, which would take account of wire self-field effect and lead to a larger value of ΣI_{cw}.

Appendix II Cable R(293) and RRR Determination

As in the case of wires, the cable resistance at 293 K and that at 10 K is determined using the same set-up used for Ic determination. The residual resistance ratio, RRR, is defined to be R(293)/R(10). R(293) is measured with an accuracy of 0.5%; R(10) is measured with an accuracy of 2%.

The quantity RRR provides a measure of the state of anneal of the copper matrix. It may be used to check that a cable has been given a post-cabling heat treatment in order to facilitate coil winding, if this has been specified. Such cables have RRR values over 100, whereas, typically, cables have values around 70, if the wire has had a final anneal, and 35 if it has not been annealed after the final drawing stages.

The room temperature measurement is made using a DC current of 1 A, and voltage contacts 61 cm apart (see Figure I.2). A thermocouple device of 0.1^{0}C accuracy is used to determine the ambient temperature. Normally occurring room temperature variations produce significant variations in the measured resistance. Designating this resistance as R_m and the ambient temperature as t(^{0}C), the resistance at the reference temperature of 293 K is calculated as follows:

$$R(293) = \frac{R_m}{1 + 0.0039(t - 20)}$$

The effect of the Nb-Ti is negligible for the purpose of this correction

The low temperature measurement is a dynamic one, made by inducing a superconducting-normal state quench while the cable is carrying current. Referring to Figure I.2, a quench is triggered in Cable A, for example, by means of heater HA. The resulting waveform observed at nearby voltage taps, A2-A3 or A3-A4, consists of three parts: a superconducting state baseline voltage, a linear ramp voltage corresponding to the passage of the superconducting-normal interface between the voltage taps, and a slowly increasing signal characteristic of the normal state resistance. The latter increases in time due to normal state heating. However, at first the voltage is almost constant due to the residual resistance characteristic of the copper. Thus, there is a kink in the voltage waveform at the beginning and at the end of the linear ramp portion. The voltage difference between these two points equals the current times the residual resistance of the section of cable between the voltage taps. The resistance per centimeter is determined for two pairs of taps (A2-A3 and A3-A4 in the above illustration) and averaged. The taps are relatively close to the heater in order to minimize the effect of current fall-off which results from the increase of normal state resistance as the quench propagates. The usual specification is for zero magnetic field. However, the above measurement may be made in an external field, in order to determine the magneto-resistance effect. Routinely only the resistance in zero field is measured.

Appendix III Copper/Superconductor Ratio

The copper/superconductor ratio of the cable is determined in nearly the same manner as for the wire where the copper: superconductor volume ratio (x) is calculated from R(293) and RRR by means of the formula

$$x = \frac{1 - R(293)\,A/\rho_s}{R(293)\,A/\rho_{Cu} - 1}$$

where R(293) = resistance of the strand at 293K in ohms/m

ρ_{Cu} = resistivity of the copper at 293K, in ohm · m

$$= r_i \frac{RRR}{(RRR-1)}$$

r_i = resistivity of pure copper at 293K

$= 1.682 \times 10^{-8}$ ohm · m

ρ_s = resistivity of Nb-Ti at 293K

$= 60 \times 10^{-8}$ ohm · m

and A = wire cross section area in m^2

$= \pi d^2/4$ (d = wire diameter in m)

The same formulas are used but with two exceptions:

a) The area is that of all the wires, viz., $N\pi d^2/4$.

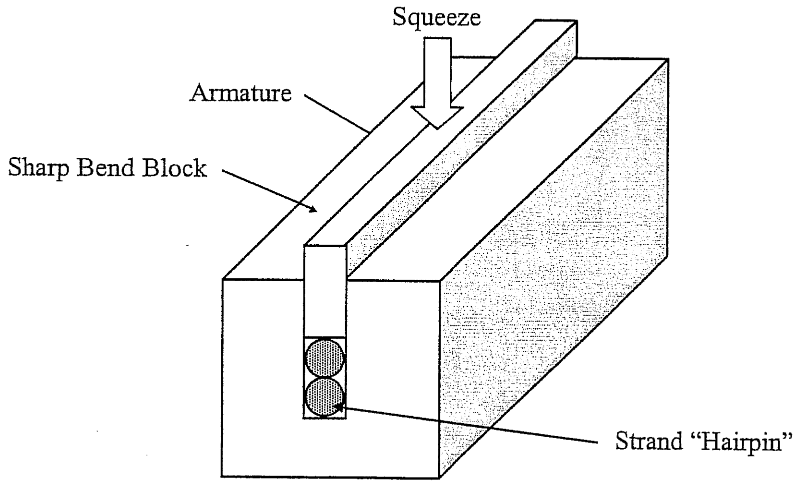
b) The spiral path of the wires necessitates applying a length correction to the measured value of R(293). For HGQ conductor R(293) is replaced by 1.049 × R(293) in the formula for the inner cable and 1.056*R(293) for the outer cable.

The resistance determination of Cu/SC for cables is routinely done in the BNL short sample test procedure and serves as an accurate check on the wire data. Cable and wire Cu/SC values agree to better than 2% in well-behaved cases, i.e. those in which there have been no errors in the strands used for cabling. This determination is, therefore, an important quality control check.

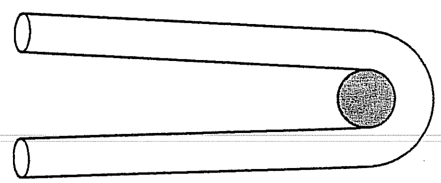
Appendix IV Sharp Bend Test

The sharp bend procedure is to simulate the deformation of the strand that may occur during cabling.

1. Fabricate a test fixture consisting of a slot in a metal block plus an armature that freely slides in the slot, as indicated in inset A1 below.



2. Cut a length of strand sample approximately 20 cm long. Bend the strand sample in half over a rod approximately 2 mm in diameter as indicated below.



3. Remove the rod and place the bent sample in the slot of the fixture as indicated in inset A1. Slide the armature into the slot of the fixture to squeeze the bent sample to the value of 2.6 mm (two strand diameters) to obtain a hairpin shape.
4. Examine the bend region at a magnification of at least 10X under a lighting level of at least 1076 lux and verify that the surface of the copper is not cracked, split, or otherwise deformed to prevent successful cabling.

5. Etch the bend region in dilute nitric acid and examine the filaments at a magnification of at least 10X and a lighting level of at least 1076 lux and verify that no filaments have been broken.

NOTES: (UNLESS OTHERWISE SPECIFIED)

1. THIS IS A CRYOGENIC VACUUM COMPONENT.
2. CLEANING PROCEDURE : PER VENDOR SPECIFICATION WITH LBNL APPROVAL.
3. PACKAGING AND STORAGE PROCEDURE OF THE COMPONENTS: PER VENDOR SPECIFICATION WITH LBNL APPROVAL.
4. DIMENSIONS AND TOLERANCING PER ANSI Y14.5M-1982. UNITS ARE IN INCHES [mm] UNLESS OTHERWISE SPECIFIED.
5. USE OF SULFUR OR SILICONE BEARING OILS, LUBRICANTS, OR COOLANTS ARE STRICTLY PROHIBITED.
6. USE OF RESIN OR RUBBER BONDED ABRASIVES UNDER POWER IS STRICTLY PROHIBITED. USE VITREOUS BONDED ABRASIVES ONLY.
7. VENDOR SUGGESTED CHANGES TO TOLERANCES TO FACILITATE FABRICATION OR ASSEMBLY; SUBECT TO LBNL APPROVAL.

DWG. NO.	SIZE	REV.	SH.
25I6664	A	1	

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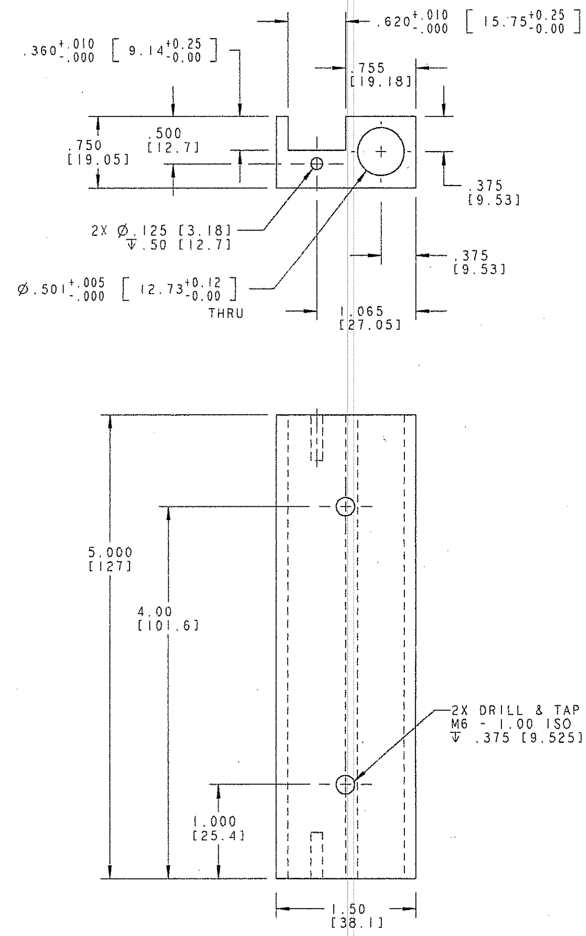
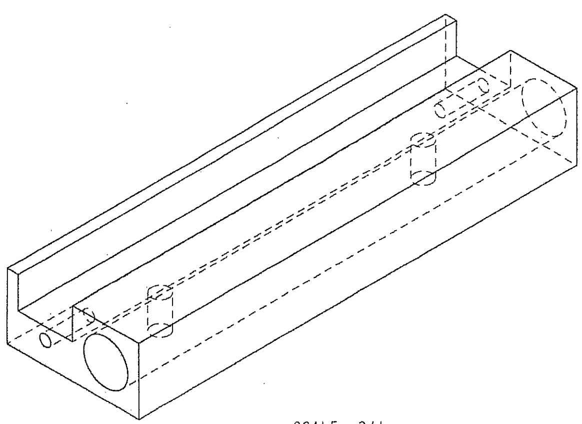
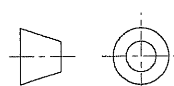




SCALE 2/1



THIRD ANGLE PROJECTION

REV	DWG	CHK	ZONE	DATE	CHANGES
A	ARH	DPO		9/19/02	INITIAL RELEASE

UNLESS OTHERWISE SPECIFIED — TOLERANCES: X.X ± 0.1; X.XX ± 0.03; X.XXX ± 0.010; FRAC. ± 1/64; Angles ± 1.00°; FINISH 125/

DO NOT SCALE PRINT

THREADS ARE CLASS 2
CHAMFER ENDS OF ALL SCREW THREADS 35°
CUT ROUND, 1.5 THREAD RELIEF ON MACHINED THREADS
BREAK EDGES .016 MAX. ON MACHINED WORK
REMOVE BURRS, WELD SPLATTER & LOOSE SCALE
IN ACCORDANCE WITH ASME Y14.5M & B46.1

SHOP ORDERS — NO. REQD 6; SURFACE TREATMT -; IDENT METHOD TAG; PROJECT NUMBER N/A; PROJECT NAME N/A; DWN BY S.Bartlett 04-Jun-02; CHK BY D.OSHATZ DATE 16-Sep-02; APP BY D.OSHATZ DATE 16-Sep-02

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LHC IR FEEDBOX
ELECTRICAL
SOLDER BOX

DWG. TYPE: PART; SHOWN ON: -; SCALE: 1/1; DO NOT SCALE PRINTS; SHEET 1 OF 1
DESIGN ACCT. NO.: 75LCE3; CATEGORY CODE: LH2004; DWG. NO.: 25I6664; SIZE: A

DESCRIPTION	MATERIAL	MAT. LOCATION
BAR, 1/2" X 1/4"	ALUM 6061	-

NOTES: (UNLESS OTHERWISE SPECIFIED)

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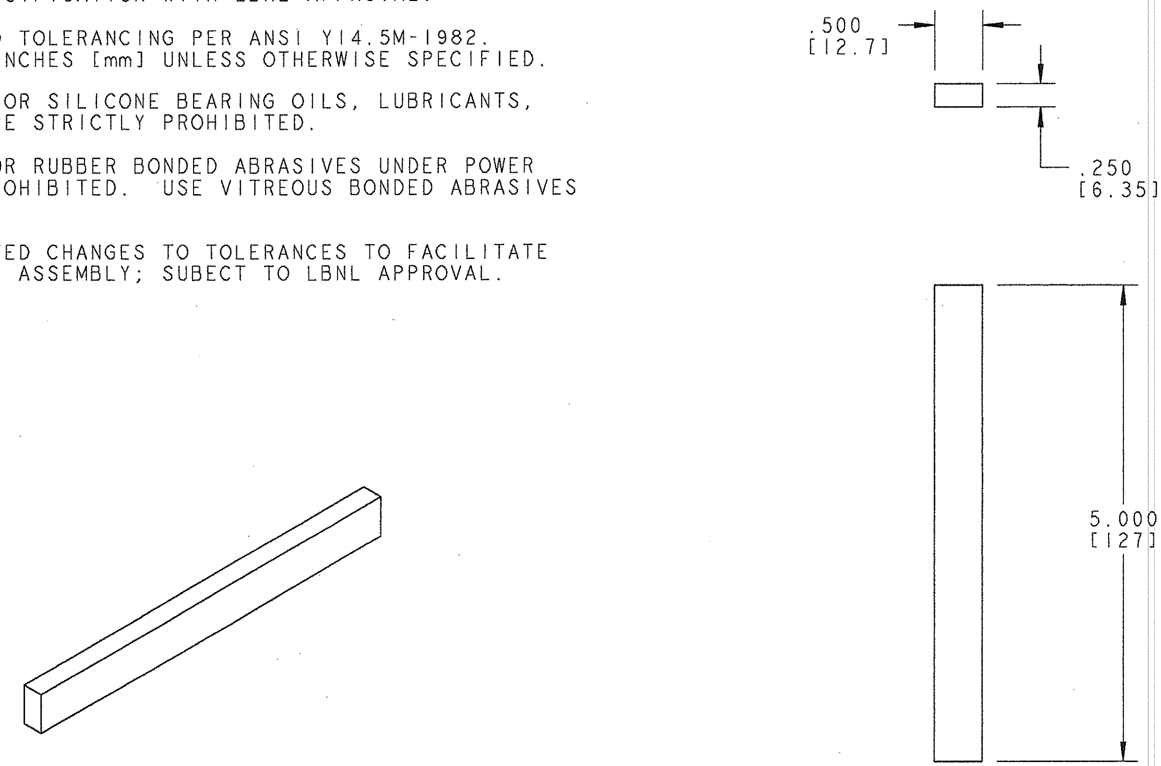

THIRD ANGLE PROJECTION

REV	DWG	CHK	ZONE	DATE	CHANGES
A	ARH	DPO		9/16/02	INITIAL RELEASE

UNLESS OTHERWISE SPECIFIED

TOLERANCES		
X.X ± 0.1	FRAC. ± 1/64	
X.XX ± 0.03	Angles ± 1.00°	
X.XXX ± 0.010	FINISH 125/(µin)	

DO NOT SCALE PRINT

THREADS ARE CLASS 2
CHAMFER ENDS OF ALL SCREW TREADS 30°
CUT ROUND, 1.5 THREAD RELIEF ON MACHINED THREADS
BREAK EDGES .016 MAX. ON MACHINED WORK
REMOVE BURRS, WELD SPLATTER & LOOSE SCALE
IN ACCORDANCE WITH ASME Y14.5M & B46.1

SHOP ORDERS
SER NO. -
ACCT NO. | NO. REQD | DATE ISSD -
DEL TO | DATE REQD -
SURFACE TREATMT -
IDENT METHOD TAG
PROJECT NUMBER N/A
PROJECT NAME N/A
DWG BY S.Bartlett DATE 11-Jun-02
CHK BY D.OSHATZ DATE 16-Sep-02
APR BY D.OSHATZ DATE 16-Sep-02

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LHC IR FEEDBOX
ELECTRICAL
PUSH BLOCK

MICROFILMED: | DWG. TYPE: PART | SHOWN ON: - | SCALE: 1/1 | DO NOT SCALE PRINTS
SHEET 1 OF 1
PATENT CLEAR: | DESIGN ACCT. NO. Z5LCE3 | CATEGORY CODE LH2004 | DWG. NO. 25I6673 | SIZE | REV. A

DWG. NO.	SIZE	REV.	SH.
25I6673		A	1

DESCRIPTION	MATERIAL	MAT. LOCATION
BAR	NEMA G10	-

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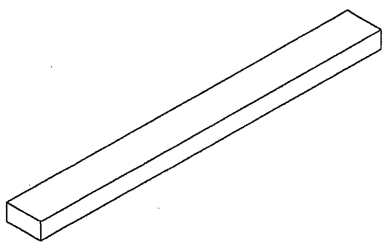

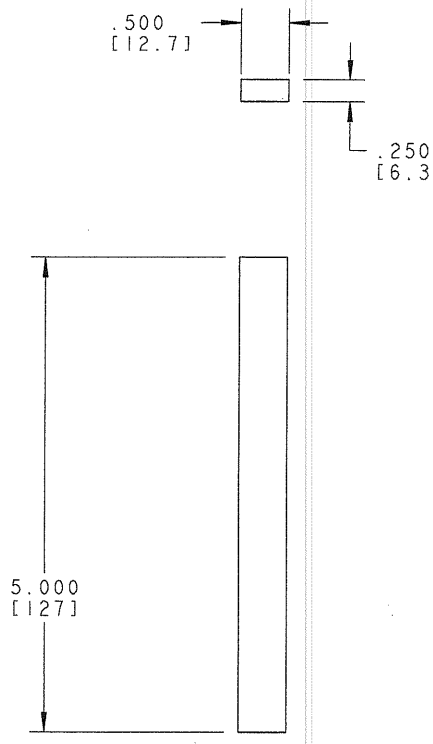

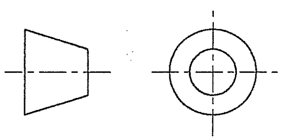

THIRD ANGLE PROJECTION

REV	DWG	CHK	ZONE	DATE	CHANGES
A	ARH	DPO		9/16/02	INITIAL RELEASE

UNLESS OTHERWISE SPECIFIED

TOLERANCES		
	X.X ± 0.1	FRAC. ± 1/64
	X.XX ± 0.03	Angles ± 1.00°
	X.XXX ± 0.010	FINISH 125

DO NOT SCALE PRINT
THREADS ARE CLASS 2
CHAMFER ENDS OF ALL SCREW THREADS 30°
CUT ROUND, 1.5 THREAD RELIEF ON MACHINED THREADS
BREAK EDGES .016 MAX. ON MACHINED WORK
REMOVE BURRS, WELD SPLATTER & LOOSE SCALE
IN ACCORDANCE WITH ASME Y14.5M & B46.1

SHOP ORDERS

ACCT NO.	NO. REQD 6	SER NO. -
DEL TO		DATE ISSD -
SURFACE TREATMT -		DATE REQD -
IDENT METHOD TAG		
PROJECT NUMBER N/A		
PROJECT NAME N/A		
DWG BY S.Bartlett		
CHK BY D.OSHATZ		DATE 16-Sep-02
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ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA - BERKELEY

LHC IR FEEDBOX
ELECTRICAL
PUSH BLOCK

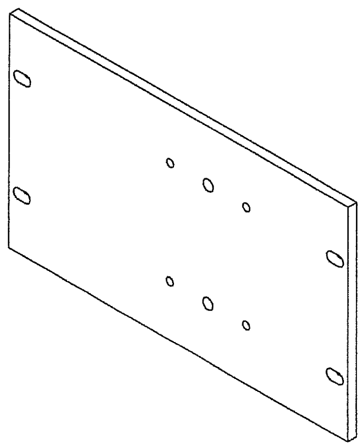
MICROFILMED:	DWG. TYPE	SHOWN ON	SCALE: 1/1	DO NOT SCALE PRINTS
	PART	-	SHEET 1 OF 1	
PATENT CLEAR:	DESIGN ACCT. NO.	CATEGORY CODE	DWG. NO.	SIZE / REV.
	-	LH2004	25I6683	A

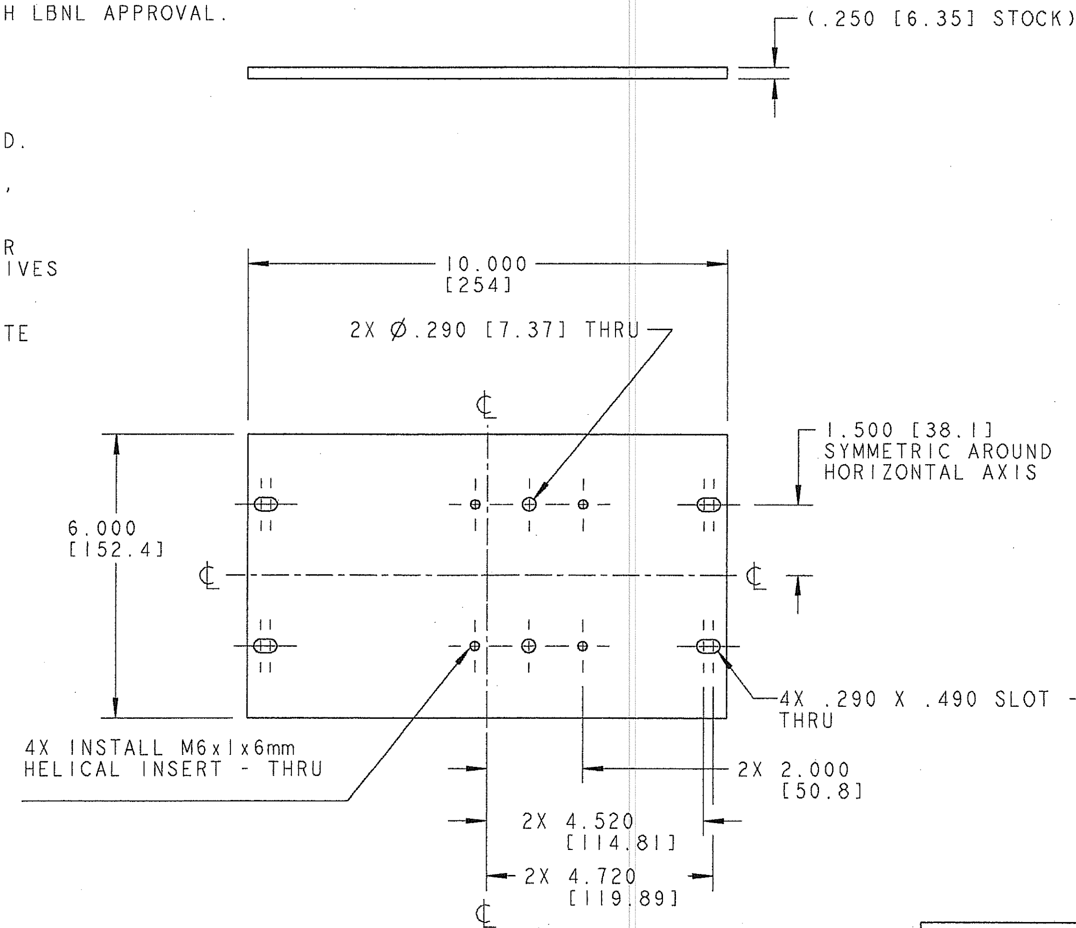
DWG. NO.	SIZE	REV.	SH.
25I6683		A	1

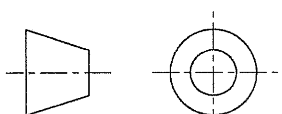
DESCRIPTION	MATERIAL	MAT. LOCATION
PLATE, 1/4"	NEMA G10	-

NOTES: (UNLESS OTHERWISE SPECIFIED)

1. THIS IS A CRYOGENIC VACUUM COMPONENT.
2. CLEANING PROCEDURE : PER VENDOR SPECIFICATION WITH LBNL APPROVAL.
3. PACKAGING AND STORAGE PROCEDURE OF THE COMPONENTS: PER VENDOR SPECIFICATION WITH LBNL APPROVAL.
4. DIMENSIONS AND TOLERANCING PER ANSI Y14.5M-1982. UNITS ARE IN INCHES [mm] UNLESS OTHERWISE SPECIFIED.
5. USE OF SULFUR OR SILICONE BEARING OILS, LUBRICANTS, OR COOLANTS ARE STRICTLY PROHIBITED.
6. USE OF RESIN OR RUBBER BONDED ABRASIVES UNDER POWER IS STRICTLY PROHIBITED. USE VITREOUS BONDED ABRASIVES ONLY.
7. VENDOR SUGGESTED CHANGES TO TOLERANCES TO FACILITATE FABRICATION OR ASSEMBLY; SUBECT TO LBNL APPROVAL.







THIRD ANGLE PROJECTION

REV	DWG	CHK	ZONE	DATE	CHANGES
A	ARH	DPO		9/16/02	INITIAL RELEASE

UNLESS OTHERWISE SPECIFIED

TOLERANCES		
	X.X ± 0.1	FRAC. ± 1/64
	X.XX ± 0.03	Angles ± 1.00°
	X.XXX ± 0.010	FINISH 125 √(μin)

DO NOT SCALE PRINT

THREADS ARE CLASS 2
CHAMFER ENDS OF ALL SCREW THREADS 30°
CUT ROUND, 1.5 THREAD RELIEF ON MACHINED THREADS
BREAK EDGES .016 MAX. ON MACHINED WORK
REMOVE BURRS, WELD SPLATTER & LOOSE SCALE
IN ACCORDANCE WITH ASME Y14.5M & B46.1

SHOP ORDERS
ACCT NO. — NO. REQD 2
DEL TO
SURFACE TREATMT -
IDENT METHOD TAG
PROJECT NUMBER N/A
PROJECT NAME N/A
DWG BY S.Bartlett
CHK BY D.OSHATZ — DATE 16-Sep-02
APR BY D.OSHATZ — DATE 16-Sep-02
SER NO. -
DATE ISSD -
DATE REQD -

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA - BERKELEY

LHC IR FEEDBOX
ELECTRICAL
SOLDER BOX MOUNT PLATE, 10"

MICROFILMED:
PATENT CLEAR:

DWG. TYPE	SHOWN ON	SCALE: 1/2	DO NOT SCALE PRINTS
PART	-	SHEET 1 OF 1	
DESIGN ACCT. NO.	CATEGORY CODE	DWG. NO. / SIZE	REV.
Z5LCE3	LH2004	25I6703	A

DWG. NO.	SIZE	REV.	SH.
25I6703	A	A	1

DESCRIPTION	MATERIAL	MAT. LOCATION
PLATE, 1/4"	NEMA G10	-

NOTES: (UNLESS OTHERWISE SPECIFIED)

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3. PACKAGING AND STORAGE PROCEDURE OF THE COMPONENTS: PER VENDOR SPECIFICATION WITH LBNL APPROVAL.
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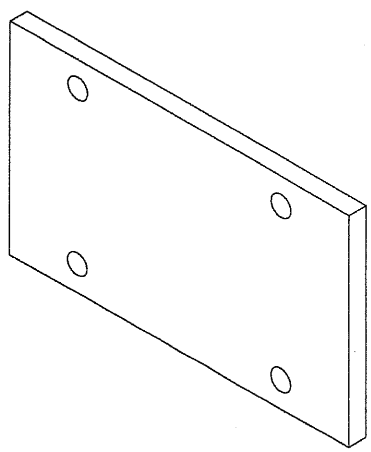

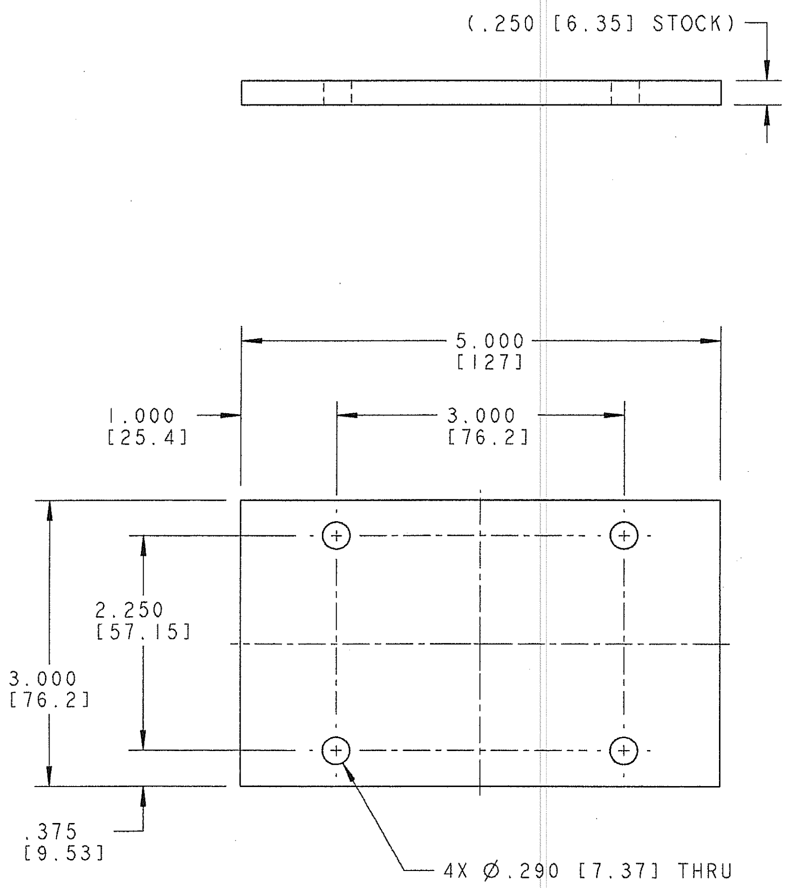

THIRD ANGLE PROJECTION

REV	DWG	CHK	ZONE	DATE	CHANGES
A	ARH	DPO		9/16/02	INITIAL RELEASE

UNLESS OTHERWISE SPECIFIED

TOLERANCES		
	X.X ± 0.1	FRAC. ± 1/64
	X.XX ± 0.03	Angles ± 1.00°
	X.XXX ± 0.010	FINISH 125 µin

DO NOT SCALE PRINT

THREADS ARE CLASS 2
CHAMFER ENDS OF ALL SCREW THREADS 30°
CUT ROUND, 1.5 THREAD RELIEF ON MACHINED THREADS
BREAK EDGES .016 MAX. ON MACHINED WORK
REMOVE BURRS, WELD SPLATTER & LOOSE SCALE
IN ACCORDANCE WITH ASME Y14.5M & B46.1

SHOP ORDERS

ACCT NO.	NO. REQD 6	SER NO. -
DEL TO		DATE ISSD -
		DATE REQD -
SURFACE TREATMT -		
IDENT METHOD TAG		
PROJECT NUMBER N/A		
PROJECT NAME N/A		
DWG BY S.Bartlett		DATE 11-Jun-02
CHK BY D.OSHATZ		DATE 16-Sep-02
APR BY D.OSHATZ		DATE 16-Sep-02

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA - BERKELEY

LHC IR FEEDBOX
ELECTRICAL
CLAMP PLATE

MICROFILMED:	DWG. TYPE	SHOWN ON	SCALE: 1/1	DO NOT SCALE PRINTS
	PART	-	SHEET 1 OF 1	
PATENT CLEAR:	DESIGN ACCT. NO.	CATEGORY CODE	DWG. NO.	SIZE / REV.
	Z5LCE3	LH2004	25I6643	A

DWG. NO.	SIZE	REV.	SH.
25I6643		A	1

DESCRIPTION	MATERIAL	MAT. LOCATION
PLATE, 1/4"	NEMA G10	-

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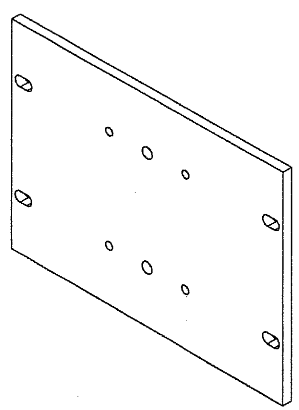

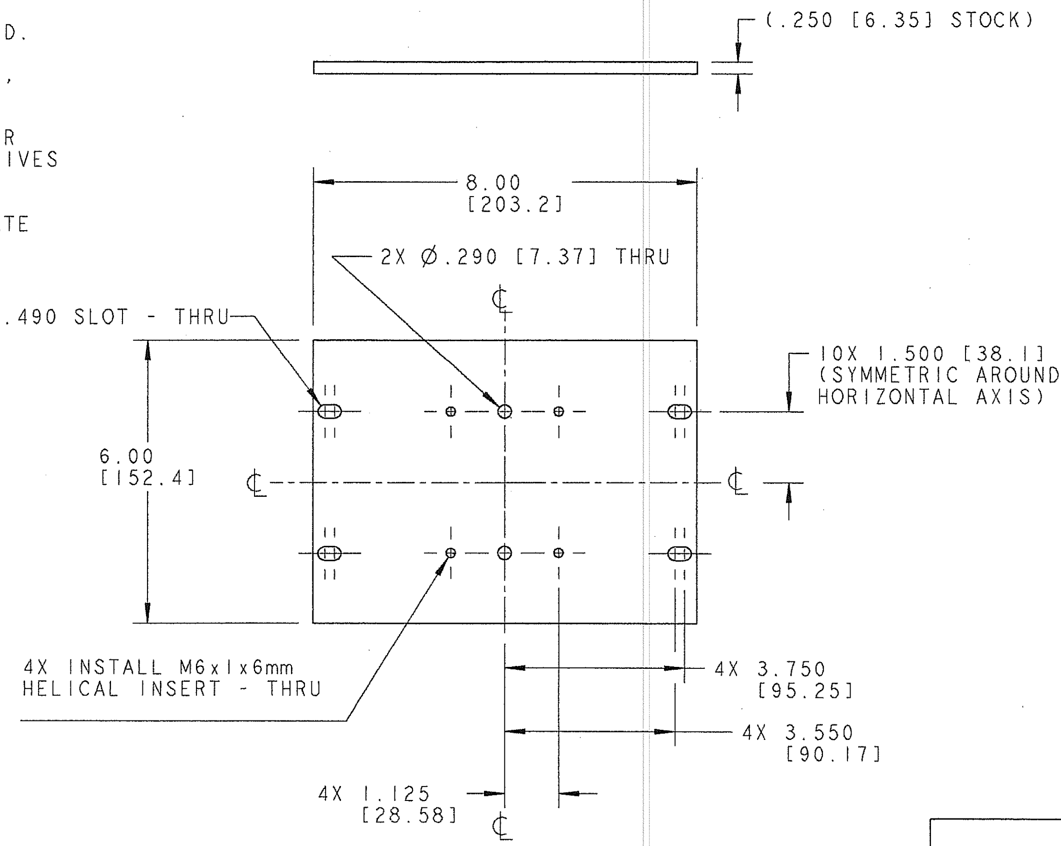

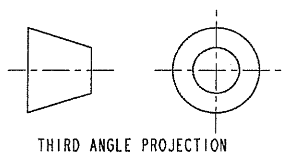

REV	DWG	CHK	ZONE	DATE	CHANGES
A	ARH	DPO		9/16/02	INITIAL RELEASE

UNLESS OTHERWISE SPECIFIED

TOLERANCES	
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X.XX ± 0.03	Angles ± 1.00°
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SHOP ORDERS

SER NO. -
ACCT NO. | NO. REQD 4 | DATE ISSD -
DEL TO | DATE REQD -
SURFACE TREATMT -
IDENT METHOD TAG
PROJECT NUMBER N/A
PROJECT NAME N/A
DWG BY S.Bartlett | DATE 11-Jun-02
CHK BY D.OSHATZ | DATE 16-Sep-02
APR BY D.OSHATZ | DATE 16-Sep-02

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA - BERKELEY

LHC IR FEEDBOX
ELECTRICAL
SOLDER BOX MOUNT PLATE 8"

MICROFILMED:	DWG. TYPE	SHOWN ON	SCALE: 1/2	DO NOT SCALE PRINTS
	PART	-	SHEET 1 OF 1	
PATENT CLEAR:	DESIGN ACCT. NO.	CATEGORY CODE	DWG. NO.	SIZE / REV.
	Z5LCE3	LH2004	25I6633	A

DWG. NO.	SIZE	REV.	SH.
25I6633		A	1