STANFORD LINEAR ACCELERATOR CENTER

SPECIFICATION

STANFORD SYNCHROTRON RADIATION LABORATORY

Cat. Code: S30732	Specification No. PS-444-400-10R1	Page1 of 16
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First Line:
SPEAR3

Second Line:
Magnet System

Title:
Quadrupole Magnet Coil Production

Quadrupole

COIL

Specification

四极铁

线圈

生产说明书

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Update / 修改

2.2.4.1 IHEP Impregnation Formulation / 高能所环氧配方
Filler materials are added. 增加了添加剂

2.3 Water Fittings / 水接头
Block was stainless steel, is OFHC copper. 水嘴材料从不锈钢改为无氧铜

3.5 Brazing / 钎焊
Hard solder is defined. 规定了焊条品牌

3.6 Fittings / 水接头
Loctite type and used location are defined. 明确了密封材料Loctite的牌号和使用的部位

4.2.3.2 Pressure test / 压力检测
Was 450psi dry air pressure, is water pressure. 将450psi气压试验改为水压试验

1. GENERAL ／ 概况

This specification is present in both English and Chinese text; in case of differences, the English version shall be used.

本说明含中英文两种文字，如两种文字有不符之处，以英文为准。

1.1 Scope of the Specification ／ 说明书范围

This specification outlines the minimum requirements governing the fabrication, inspection and testing of the magnet main coils and modulation system coils for the SPEAR3 quadrupole production magnets and spare coils.

本说明书概括了SPEAR3工程四极铁批量铁主线圈、调制线圈以及备用线圈的制造、检验和测量的基本要求。

1.1.1 Applicable Document ／ 使用文件

Drawing SA444-403-35	Inner Coil Potting 15Q
Drawing SA444-403-47	Outer Coil Potting 15Q
Drawing SA444-403-43	QMS Coil 15Q
Drawing SA444-403-33	Inner Coil Potting 34Q
Drawing SA444-403-45	Outer Coil Potting 34Q
Drawing SA444-403-41	QMS Coil 34Q
Drawing SA444-403-34	Inner Coil Potting 50Q
Drawing SA444-403-46	Outer Coil Potting 50Q
Drawing SA444-403-42	QMS Coil 50Q
Drawing SA444-403-36	Inner Coil Potting 60Q
Drawing SA444-403-48	Outer Coil Potting 60Q
Drawing SA444-403-44	QMS Coil 60Q

1.1.2 Reference Document ／参考文件

Engineering Note M320 Quadrupole Engineering Design Summary / 四极铁工程设计总括

1.2 Scope of Work ／ 工作范围

IHEP shall fabricate all the coils required for the SPEAR3 quadrupole magnets. IHEP shall design and fabricate tooling required to produce the coils; purchase the copper conductor of quadrupole modulation system (QMS) coil, cloth and tape insulation and water fittings and specify the epoxy formulation for potting coils. IHEP shall write the technical specification for the purchase of the QMS copper conductor. This specification shall be reviewed by SLAC. The final form of the specification shall be the responsibility of IHEP. IHEP shall provide assembly drawing of coil winding fixture and potting mold. IHEP shall develop inspection documentation (travelers) and provide all equipment for quality assurance tests and measurements of electrical and hydraulic parameters and perform all procedures, tests and measurements and record the results on the travelers.

高能所应生产SPEAR3四极铁所需要的所有线圈。高能所应设计和制造生产线圈所需要的工装；采购调制线圈(QMS)铜导线、绝缘带、水接头和制定线圈浇注的环氧配方。高能所还应书写采购QMS铜线的技术要求，这一材料需经SLAC审阅后由高能所最後定稿。高能所应提供给SLAC线圈的绕线模和浇注模的总图。高能所应制定质检文件（跟踪卡），并提供全套质检和电、水测量设备，并实施检验和测量。所有结果应记录于跟踪卡。

1.2.1 Quantities ／数量

There are four (4) lengths of quadrupoles. A set of coils for a SPEAR3 quadrupole consists of four (4) each of Outer Coils, four (4) each of Inner Coils containing the QMS Coils.

四极铁共有四（4）种不同的长度。每块SPEAR3四极铁的一套线圈 含四（4）个外线圈，四（4）个内线圈（含调制线圈）。

1.3 Coil Design ／线圈设计

The following computed parameters are based on the coil design summarized in Engineering Note M320 listed in section 1.1.2 and the drawings listed in section 1.1.1 of this specification.

下列计算数据来自本说明书1. 1. 2款所列工程设计书M320和1. 1. 1款所列图纸中出概括的线圈设计参数。

Main Coil Design Parameter

Max. Conductor Cross Section ／导线最大截面 4.86 mm X 4.86 mm
Conductor Corner Radius ／导线圆角半径 1 mm
Conductor Hole Diameter／导线孔半径 3.18 mm
Conductor Material／导线材料 OFHC copper/ 无氧铜

Quadrupole Type / 铁名	60Q		50Q		34Q		15Q	
Coil Type /内、外线圈	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Number of Turns per Coil/匝数	64	60	64	60	64	60	64	60
Continuous Length per Coil/导线长（m）	101.5	105.5	88.7	93.5	68.2	74.3	43.9	51.5
Max. Current (A)/最大电流	74.1		88.3		88.3		88.3	
Max. String Voltage (V)/ 最大总电压	330		604		540		361	
Max.Power per Coil (kW)/ 线圈最大功率	0. 7	0. 73	0. 87	0. 91	0. 67	0. 73	0. 43	0. 50
Inductance (mH) / 电感	2.12	2.01	1.79	1.72	1.27	1.26	0.64	0.71
Resistance at 40° C (mΩ)/电阻	127.4	132.4	111.3	117.3	85.6	93.2	55.1	64.6
Maximum Water Pressure (psi)/ 最大水压	250							
Design Water Δp per Coil (psi)/ 设计水压降	150							
Water Flow @ Δp150 @20°C (gpm)/水流量	0.16	0.15	0.17	0.16	0.20	0.19	0.26	0.23

Modulation System Coil Design Parameter

Max. Conductor Cross Section ／导线最大截面 3.55 mm X 2 mm
Conductor Corner Radius ／导线圆角半径 0.65 mm
Conductor Material／导线材料 OFHC copper/ 无氧铜

Quadrupole Type / 铁名	60Q	50Q	34Q	15Q
Number of Turns per Coil/匝数	24			
Continuous Length per Coil/导线长（m）	36	31	23	14
Max. Current (DC Amp)/最大电流	3.65	7.07	11.86	16.42
Peak Voltage @ 2 Hz (V)/ 电压峰值	1. 68	2. 79	3. 46	2.79
Peak Voltage @ 10 Hz (V)/ 电压峰值	4. 05	6. 58	7. 63	5. 01
Max.Power per Coil (W)/ 线圈功率	1. 31	4. 27	9. 01	10. 53
Inductance (mH) / 电感	16.4	13.7	9.3	4.1
Resistance at 40° C (mΩ)/电阻	98.55	85.30	64.05	39.02

2. MATERIALS AND PARTS ／材料和零部件

2.1 Conductor／导线

The minimum length of segments of copper conductor ordered must be long enough to wind a single coil with no brazed joints and provide enough material for clamping and tensioning during winding. The total quantity of copper conductor delivered must be sufficient for contingency to cover possible damage, loss or coil failure.

订购导线的分段长度要能保证每个线圈的连续缠绕，不留焊点，并外加足够端部拉紧余量。导线的总采购量一定要考虑到损耗、损伤和线圈报废等各种意外情况。

2.1.1 Conductor Test ／导线检验

2.1.1.1 Main Coil Conductor ／主线圈

The minimum performance parameters of finished main coils affect the performance of the magnet and impact the requirements for the power supplies and the cooling system in the SPEAR3 facility, therefore certain minimum certifications and tests are requested for the main coil conductor delivered from SLAC.

由于主线圈的最低性能指标关系到磁铁的运行性能，并对SPEAR3的电源和水冷系统有直接影响，故建议至少对由SLAC采购、到货的主线圈导线下述指性进行标验收检验。

2.1.1.1.1 Ball Test ／球试

In order to verify the continuity of the cooling channel, ball test shall be performed on each conductor segment. A steel ball with 60% to 70% of the hole diameter is blown through the conductor using pressurized dry air.

为了检验导线冷却水孔的连续性，每一分段导线都应用干燥压力气将直径为孔径60%或70%的钢球从其水孔内吹过。

2.1.1.1.2 Hardness Test／硬度检测

Annealed copper conductor is required in order to minimize winding and bending the difficulties. A Rockwell hardness test for annealed copper shall be specified to assure that the delivered conductor is fully annealed.

为了便于线圈的缠绕和弯转，导线应为经退火处理的软铜导线。应规定软铜的洛氏硬度指标，对到货导线进行检验。

2.1.1.2 Visual Inspection／导线绝缘检验

Visual inspection of the conductor before the winding of each coil shall be performed to locate any pre-coated insulation damage which will cause turn to turn short.

每个线圈绕制前，都应对导线的预包／涂绝缘层进行检验，以发现会引起匝间短路的绝缘层破伤。

2.2 Insulation ／绝缘

2.2.1 Pre – Insulation ／预绝缘涂层

2.2.1.1 Main Coil ／主线圈

Double dacron polyester glass fiber per NEMA spec MW46-C, 0.19mm thick.

双层涤纶玻璃纤维绝缘涂层，涂层厚度0.19毫米，需符合NEMA手册MW46-C款性能要求。

2.2.1.2 Modulation System Coil ／调制线圈

0.16 mm thick pre- insulated polyester insulation, thermal class 150C or higher.

0.16毫米厚聚脂绝缘漆,耐温150摄氏度或更高。

2.2.2 Ground Wrap Material ／对地绝缘材料

2.2.2.1 Main Coil ／主线圈

Ground Wrap Insulation	1.0" wide x 0.01" thick CNF Fiberglass Woven Tape
对地绝缘带：	CNF玻璃纤维布胶带1.0英寸宽，0.01英寸厚

2.2.2.2 Modulation System Coil ／调制线圈

Ground Wrap Insulation	0.5" wide x 0.01" thick CNF Fiberglass Woven Tape
对地绝缘带：	CNF玻璃纤维布胶带0.5英寸宽，0.01英寸厚

2.2.3 Fillers ／填充物

Voids in spaces between the ground wrapped coil and the potting mold must be filled in order to avoid large volumes of unfilled epoxy. These voids shall be filled with glass cloth, glass roving or cut pieces of epoxy fiberglass (US designation NEMA G-10).

线圈对地绝缘和环氧浇注模之间的空隙部分应加填充物，以避免过厚的纯环氧层。这些填充材料应该是玻璃丝带、布或小块的玻璃纤维层压环氧（美国产品为NEMA G-10）。

2.2.4 Impregnation ／环氧浇注

2.2.4.1 IHEP Impregnation Formulation ／高能所环氧配方

The following is a description of the formulation used by IHEP for the PEPII Low Energy Ring (LER) quadrupole and dipole coils. This formulation was approved by SLAC management as being chemically similar to the SLAC standard formulation and provide mechanical properties after curing equivalent to the SLAC potting formulation. It can be used to vacuum impregnate the SPEAR3 quadrupole coils.

Element	Vendor	Parts by Weight
i. Resin		
Epoxy 616 (eq. to DER 332)	Shanghai Epoxy Co.	100
ii. Hardener		
HY906 (NMA)	CEBA-Geigy Co. Switzerland	94
iii. Flexibilizer		
Polyester 304	Shanghai Epoxy Co.	30
iv. Accelerator		
DMP-30	Fluka Co. Germany	0.7
v. Filler		
Alumina (Al_2O_3)	Henan Micro Powder Co.	180
Silicon Powder (SiO_2)	Huzhou Sili Powder Co.	40
Decolorizing Carbon (Disperser)	Henan Micro Powder Co.	6

以下为高能所用于PEPII低能环二极和四极铁线圈的配方。该配方已经SLAC认定其化学成分和固化后的机械性能与SLAC配方相仿。该配方可用于四极铁线圈的真空环氧浇注。

配料	厂商	配比
i. 树脂		
环氧616(等同于DER332)	上海环氧厂	100
ii. 固化剂		
HY906(NMA)	CEBA-GeigyCo. 瑞士	94
iii. 软化剂		
304聚脂	上海环氧厂.	30
iv. 催化剂		
DMP-30	FlukaCo. 德国	0.7
v. 添加剂		
白刚玉(Al_2O_3)	河南微粉厂	180
硅微粉(SiO_2)	湖州硅粉厂	40
白碳黑(分散剂)	河南微粉厂	6

2.2.4.2 IHEP Impregnation Curing Cycle / 高能所环氧固化循环

- Bake mold with installed coil 100° C for four (4) hours before pouring epoxy.
- 120° C cure for four (4) hours plus 160° C cure for ten (10) hours.
- After cure, decrease temperature at a maximum rate of 10° C per hour until sufficiently cool to remove the coil safely from oven.
- 浇注前线圈随模加温至100摄氏度，保温四小时。
- 浇注后120摄氏度固化四小时，升温至160摄氏度保温十小时。
- 以最大每小时10摄氏度速率降炉温直至冷却到线圈可安全出炉。

2.3 Water Fittings / 水接头

In order to assure the weld quality and most importantly ease the repair in the field, OFHC copper shall be used to build the water connector block that will be brazed to the coil lead. Experience has shown that SST to copper braze connections will corrode and leak over time

and therefore is not acceptable. The water fittings attached to the finished coils shall be US standard fittings listed in the call out of Quadrupole General Assembly drawing.

经验证明，不锈钢部件与铜部件焊接经过一段时间的使用会产生铜蚀，引起渗漏，故不可采用。为了保证焊接质量和现场修复容易，与线圈引出头焊接在一起的水嘴应用无氧铜制作。与其相接的水接头应为四极铁总装图明细表中所规定的美国标准件。

3. COIL FABRICATION ／ 线圈制造

3.1 Coil Winding ／ 线圈缠绕

3.1.1 Environment ／ 环境

Coils shall be insulated and wound in an area free of metallic chips, dirt, and welding or chemical fumes. Conductors, insulation materials and wound coils shall be protected from dirt, moisture and damage during fabrication, handling and storage. Wound and ground wrapped coils shall be wrapped and protected from dirt, moisture and damage until installation into potting molds.

线圈的绕制现场应没有铁削和其他所不清洁物，应远离焊接操作和其他化学气雾。导线、绝缘带和绕好的线圈应妥善保管，避免制造、运送和储存过程中被污染、弄潮或受损。绕好并包好对地绝缘的线圈在浇注之前应有外包装，避免污染、弄潮或损伤。

3.1.2 Conductor Preparation ／ 导线准备

Conductors shall be kept clean while winding. One length of conductor shall be used for each length of one coil segment. Internal splices shall not be allowed in finished coils.

导线绕制时要保持清洁。导线的截断长度应足够绕制一个完整的线圈分层 ，绝不允许有接头。

3.1.3 Coil Winding ／线圈绕制

The coil conductor shall be pulled with sufficient tension during winding to minimize keystoning at tight bends and shall be "set" after each bend in order to assure that the coil is tightly wound and will fit into the potting mold. Meanwhile, one has to pay extreme attention to protect from pre-insulation damage.

应对导线施加足够拉紧力，以最大限度减小弯转处梯形畸变和确保在弯转处的定位，保证线圈的紧密性，或不至无法装模,同时操作人员要十分小心，不可损伤预绝缘涂层。

3.1.4 Ground Insulation

After winding, a ground wrap with half overlap shall be applied to the QMS coil. A ground wrap, afterwards, with half overlap shall be applied to bond a main inner coil and a QMS coil as a whole.

线圈绕好后，调制线圈应加对地半叠绕绝缘，而後再用半叠绕对地绝缘方式将调制线圈和内主线捆绕成一体。

3.1.5 Coil Dimension Inspection ／ 线圈外形尺寸检验

The coil outer dimension shall be inspected after ground wrapping to insure it will fit in the impregnation mold.

线圈包对地绝缘后，应检验其外形尺寸，以确保能够装入浇注模。

3.1.6 Identification ／身份号

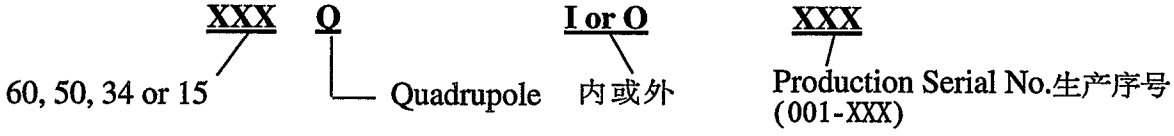
3.1.6.1 QMS Coil Number ／调制线圈序号

Each modulation coil shall be identified with its production serial number. This number shall be temporarily attached to the coil with a tag after winding and before impregnation. After impregnation, this serial number shall be recorded into the coil traveler. The serial number shall be assigned two components:

每个调制线圈都应用生产序号加以区别。线圈绕制后，环氧浇注前应该将此序号用标签拴在线圈上。环氧浇铸后，序号应记入跟踪卡。如图示，序号号应由两部分组成。

3.1.6.2 Coil Identification Number ／线圈身份号

Each coil shall be identified with a unique number. This number shall be temporarily attached to the coil with a tag after winding and before impregnation. After impregnation, this identification number shall be stenciled to the potted surface in permanent ink or paint in a location which shall be visible after the coil is installed in the magnet assembly. The identification number shall be assigned four (4) components, all coils shall share one production serial number:



每个线圈都应有自己独有的身份号。线圈绕制后，环氧浇注前应该将此身份号用标签拴在线圈上。环氧浇注后，这一身份号应该用永久墨水或漆写在线圈在磁铁总装后仍易见处。如图示，身份号应由三部分组成，所有不同长度的线圈应共用一个系列号。

3.2 Coil Impregnation ／线圈浇注

3.2.1 Environment ／环境

Impregnation coil shall be in an area free of metallic chips, dirt, and welding or chemical fumes. Impregnation compounds and ground wrapped coils shall be protected from dirt, moisture and damage during storage and handling. Temperature of impregnation facility shall be kept at 25° C± 5° C and shall be baffled to reduce excess air circulation.

环氧浇注环境应没有铁削，不洁物品和焊接或化学品烟雾。环氧配料和绕好对地绝缘的线圈应妥善保管，保证操作和储存过程中不被污染、弄潮和损伤。环氧浇注场合的温度要保持在25°C ± 5°C，要有阻断气流直接侵入的屏障物。

3.2.2 Impregnation / 浇注

3.2.2.1 Inner Coil / 内线圈

A pair of wound and ground wrapped inner main coil and QMS coils shall be installed in a vacuum potting mold suitably cleaned and prepared with a mold release compound compatible with the epoxy formulation. The two coils shall be vacuum impregnated in one solid piece with the epoxy formulation called for 2.2.4.1. Large voids between the ground wrapped coils and the potting mold shall be filled with filler called for 2.2.3. Standard procedures for vacuum impregnation shall be followed. These include mixing of the components at prescribed temperatures; vacuum deaeration of the epoxy mixture while mixing at an elevated temperature to remove bubbles which might form at the curing temperature; delivery of the epoxy to the mold under vacuum and successive venting and evacuation of the filled mold to remove bubbles. The filled mold shall be vented with suitably placed vent tubes and tipped in the curing oven to assure that bubbles can escape in these tubes. The vent tubes act like standpipes and should have sufficient fluid capacity to compensate for epoxy shrinkage in the mold during curing. The filled mold shall be cured using 2.2.4.2 curing temperature cycle for the 2.2.4.1 epoxy formulation.

将绕制并包好对地绝缘的一对内主线圈和调制线圈放入彻底清洗干净并涂了退模剂的真空浇注模内，用2.2.4.1款所述配方的环氧真空浇注成一个整体线圈。线圈与浇注模间大的空间应用2.2.3款所要求的填充物填充。真空固化过程应遵循标准固化循环工艺。这包括在工艺要求的温度下混料，在混胶过程中抽真空去泡；真空注铸，模具排气去泡。模具在适当位置安有出气管，充好胶的模具在炉内应适当倾斜，确保气泡可从排气管排出。排气管需直立，并有足够容积供补胶之用。充好胶的模具，要按为2.2.4.1款配方的环氧设计的2.2.4.2款固化循环固化。

3.2.2.2 Outer Coil / 外线圈

The ground wrapped outer main coil shall follow the standard vacuum impregnation procedure described in section 3.2.2.1.

包好对地绝缘的主外线圈应按款3.2.2.1所述标准真空环氧浇铸固化工艺浇铸。

3.3 Inspection and Repairs / 检验和返修

The impregnated coil shall be visually inspected for cracks, bubbles and voids. Easily accessible surface bubbles and voids and cracks shall be filled with epoxy. Internal cracks bridging over the space between adjacent conductors shall be repaired by drilling out or otherwise removing the cracked insulation and filling with epoxy. All repaired cracks and voids in the finished coils shall be noted and described in the travelers which accompany each coil.

浇注后的线圈应进行外观检查，观察是否有裂痕、气泡和空穴。表面浅层气泡、空穴和裂痕可直

接 用环氧修补。深入内层的、桥接 临近导线的裂痕应先用钻孔或其他方式将裂损环氧清除，而
后补环氧。所有经修补的裂痕或空穴都应在该线圈完工后记录在其跟踪卡内。

3.4 Rejections / 报废

If, as a result of visual inspection, the impregnated coil has unrepairable cracks or voids which represent a risk of turn to turn or ground shorts during tests or operation, the coil shall be rejected.

如果线圈外观检查中发现难以修复的裂痕或空穴，这些缺陷很可能导致测试或运行中出现匝间或对地短路，线圈应于报废。

3.5 Brazing / 钎焊

The impregnated coil leads shall be bent to the prescribed shape outlined in coil assembly drawing. The copper thermal interlock mounting blocks, copper busses for coil to coil and coil to power lead connections and water fitting connector shall be hard soldered to the conductors. A US standard braze filler rod (BCuP-5) which contains 15% Ag, 80% Cu and 5% P and does not use flux shall be selected for brazing of the water connector block. The appropriate cleaning and fluxing procedure for the selected hard solder should be followed in order to guarantee a good braze joint. The area of the conductor insulated by epoxy should be suitably protected to prevent burning during brazing by wrapping with wet cloth.

线圈的引出头应按线圈组装图所示尺寸委弯。温控开关固定板和线圈间、线圈与电源间连接母板以及水嘴与线圈引出头的焊接应选用美国制造的无焊剂钎焊焊条(Bcup-5)，其成分为15%Ag, 80%Cu and 5%P。应按所选焊料要求正确清洗焊接表面，选择正确焊接工艺，以确保焊点的可靠。导线环氧绝缘的部分应用湿布加以保护，使其在焊接过程中不被烧伤。

3.6 Fittings / 水接头

The prescribed water fittings shall be installed at both ends of the water fitting block of the finished main coil using Loctite PST 580 (radiation resistant) in the pipe joints. The connection between the standard Swagelock parts (water fitting and the adopter cramped on the water hose) shall not use the Loctite to enhance the sealing. The built in configuration of those parts have guaranteed the appropriate sealing. Installation must be done carefully in order to prevent any excess Loctite and dirt or chips from getting into the cooling channel and subsequently causing clogging in the channel. IHEP shall clearly mark water supply fittings and water return fittings to prevent water circuits mis-connection.

水接头应拧紧 在完工的主线圈的两端水嘴上并 用Loctite抗幅射PST580密封。安装时要十分小心，Loctite和其他藏物或碎削不能进入水孔而阻碍水循环。高能所还应将进水接头和出水接头标以不同记号，以防止接错水循环。必须提醒的是，标准Swagelock水连接部件间（水接头和挤压在水管上的阴接头之间）不允许使用Loctite加强密封，这些标准件的结构已确保了密封的可靠（多余的涂料反而破坏密封）。

4. QUALITY ASSURANCE, TESTING & DOCUMENTATION / 质量保证，检测和记录

4.1 Traveler / 跟踪卡

An inspection sheet (traveler) shall be devised by IHEP and approved by SLAC. This traveler shall include pertinent fabrication records, inspection results and electrical and pressure test data. The information included in the traveler shall include at minimum the following data.

- Modulation System Coil Serial Number.
- Inner Coil Identification Number.
- Outer Main Coil Serial Number.
- Results of visual inspections and any repairs.
- Electrical and Hydraulic test, Measurement and Inspection Result.
- Name of technicians brazing the connections and dates.
- Names of technicians winding the coil and dates.
- Names of technicians impregnating the coil and dates.

高能所应提供检验单（跟踪卡），跟踪卡应经SLAC核审。跟踪卡应包括相应的生产记录，检验结果和电、压力测量数据。跟踪卡至少要含以下内容：

- 调制线圈序号，
- 内线圈身份号；
- 外主线圈序号；
- 外观检查结果和可能的返修记录；
- 电、水检测、测量和检验结果；
- 焊接工姓名和日期；
- 绕线工姓名和日期；
- 环氧浇注工姓名和日期；

4.1.1 Filling out the Traveler / 填写跟踪卡

The traveler shall be filled out, signed and dated by the technicians performing the winding, potting, inspection, electrical tests and measurements and pressure tests and measurements of the coil. The completed traveler shall be signed and dated by the technician supervisor signifying approval of the coil for final magnet assembly.

跟踪卡应由绕线，浇注，检验，电、压力检测和测量的各操作人员填写并签名，注明日期。填写完毕的跟踪卡应由有关负责人签准，将线圈发往下一道磁铁总装工序。

4.1.2 Traveler Original / 跟踪卡原件

The original of the completed, signed and approved traveler shall accompany the coil until final magnet assembly. After magnet assembly, the completed original traveler shall be filed at IHEP.

填写完毕并经签批的跟踪卡原件应随线圈运转直至磁铁最後总装。磁铁总装完后，跟踪卡原件应由高能所保存。

4.1.3 Traveler Copies / 跟踪卡复印件

A copy of a traveler for each coil shall be packaged with other copies of completed travelers for each completed magnet and delivered to SLAC along with the magnet.

每个线圈应有一份跟踪卡复印件，与完工后磁铁的其他跟踪卡复印件汇总，随磁铁一起转交SLAC。

4.2 Main Coil Tests and Measurements ／主线圈检测和测量

The following tests and measurements shall be conducted on ground wrapped coils and impregnated coils in order to assure adequate performance of the coils during operation of the finished magnet in the accelerator.

为了确保线圈的性能以使磁铁正常运行，绕好对地绝缘的线圈，而后浇注好的线圈应进行下述检测和测量。

4.2.1 Optional Tests before Impregnation ／环氧浇注前选择性检测

Either impulse test or inductance tests of ground wrapped coils may be conducted before the coil impregnation. The impulse test voltage for the unimpregnated coil should not exceed 750V. The inductance test reading value shall be within 5% of design value showed in section 1.3 within a 750 V scale. Either test will reveal coil turn to turn short early in the fabrication cycle.

环氧浇注前，包好对地绝缘的线圈需或进行脉冲检测，或进行电感测量。未浇环氧浇铸线圈的脉冲测量电压不得超过750伏。电感测量读数在750伏尺度内应分别不应超过1.3款内所列设计电感值的5%。两种中的任一种测量都应能早期暴露线圈已存在的匝间短路隐患。

4.2.2 Tests after Impregnation ／环氧浇注后检测

4.2.2.1 Resistance measurement ／电阻测量

Coil resistance of the finished impregnated coil shall be measured with a "double bridge" to eliminate the inaccuracy due to current in the measurement circuit. The type and model number of the bridge used shall be noted in the test records. The measurement shall be made with the coil temperature uniform throughout and steady state conditions prevailing. The coil temperature shall be recorded and the resistance measurement shall be to at least three significant figures. The resistance value shall be corrected to 40° C. The acquisitive resistance of a production coil might be different from the normal value listed in section 1.3, but the deviation should not be significant. An average value of first four (4) production coils of each type coil at 40° C shall be used as a criterion for the production coil resistance measurement. Variations of resistance greater than 3% of the criterion value when corrected to 40° C indicate a possible turn-to-turn short or an incorrect number of wound turns and shall be cause for rejection.

环氧浇注后的线圈应测量其电阻值。测量仪器应为双桥电路，以消除测量循环内电流造成的影响。测量记录中应指明所用电桥的类别和型号。测量过程中，线圈要保持恒温。线圈的实测温度需作记录，测量电阻值至少为三位有效数字。电阻值要作40摄氏度标准化处理。生产线圈实测值很可能与1.3款所列设计值有出入，但偏差不应很大。实际应用时，应用每种线圈头4个生产线圈所得40摄氏度标准化处理后电阻值的平均值作为该线圈的标准值。凡生产线圈与该标准值数据相差3%以上，线圈则或可能有短路，或可能缠绕匝数有误，应予报废。

4.2.2.2 Impulse Test / 脉冲检测

The impulse test is meant to detect total and partial turn-to-turn shorts in the finished impregnated coil. The impulse test shall be performed by applying a short pulse of voltage across a combination of capacitor and the coil being tested and observing the voltage across the coil with an oscilloscope. The coil shall be at least 0.5 m away from any large metallic object in which induced eddy currents may impair test sensitivity. The rise time of the voltage pulse shall be greater than 2 μsec. in order to prevent voltage doubling due to transmission line effects. Apply low voltage (not to exceed 500 V) and observe the damped oscillatory response displayed on the oscilloscope. Raise the voltage, in several increments, to full voltage (2.2 kV). If there is no breakdown (turn-to-turn total short), the signal will increase in amplitude, but frequency and damping factor will remain constant. The coil shall be pulsed at least ten times at full voltage. There shall be no noticeable change in frequency or damping rate during these ten tests. There shall be no "grass" on the wave form due to corona. Changes in frequency or damping rate or "grass" on the wave form are indications of a full or partial turn-to-turn short and are cause for coil rejection. Photographs of the damped response shall be taken at the low voltage level and at full voltage, appropriately marked with the voltage, scale factor, date, coil identification number and operator. The two photographs (low and high voltage traces) shall be entered into the test record by affixing to the traveler.

脉冲检测的目的是发现环氧浇注后的线圈可能的完全性或部分性匝间短路。脉冲检测可通过向被测线圈和一个电容的并联电路施加脉冲电压的方式进行，通过示波仪观察电压通过线圈所产生的波形。线圈至少要距离其他大体积铁物0.5米以外，以防其感应涡流干扰测量的准确性。脉冲施加时间应大于2μsec，以避免因输运线路影响造成电压加倍。先施加低压脉冲（不超过500伏），观测示波器屏幕减振波形；梯次增加电压至全电压（2.2kV），如果线圈没有匝间短路问题，波形信号振幅加大，而频率和减振速率将保持不变。线圈在全电压至少要脉冲十次。各次脉冲频率或减振速率不应有明显变化，也不应有由于电晕形成的“草波”。如波形频率或减振速率有变化或出现“草波”，则说明线圈有全或半短路，应予报废。低压和高压的减振波形应分别拍照，照片需标明所用电压、比例、日期、线圈身份号和检验员姓名。此两张相片应附于线圈的跟踪卡后。

4.2.2.3 High Voltage (Hipot) Test / 高压检测

A high voltage test shall be performed after the coil is impregnated. The coil shall be submerged into salt water and the test voltage shall be 2.2 kV DC for a minimum period of one minute for all quadrupole main coils. The measured leakage current shall not exceed 2 μA. In the case of inner main coil test, the QMS coil shall be grounded and inside and outside layers of inner main coil shall be serially connected.

线圈环氧浇注后要进行高压检测。被测线圈需半浸于盐水，所有四极铁检测电压均为2.2kvV直流电压，施压时间不得短于一分钟。所测漏电流值不得大于2μA。在测量内主线圈时，调制线圈应接地，内主线圈的内、外两层线圈出头应串接。

4.2.3 Test and Measurement after Installation / 连接附件后的检测和测量

4.2.3.1 Buss Lug Position / 母板位置

It is important that the bus be located reproducibly from coil to coil. The reproducibility is required in order to avoid costly fit ups during the installation of the rigid bus connections which electrically connect the coils on the assembled magnets. It is highly recommended that a fixture be designed and built for locating the buses while the leads are being bent. A second fixture should be built for measuring the location of the bus lug for the finished coil relative to a datum that can be a feature on the external surface of the impregnated coil. These fixtures will ensure reproducibility from coil to coil.

每个线圈母线板位置的一致性十分重要，这样将来隧道电源线与磁铁线圈的连接会快捷许多。母线板相对于线圈出线头弯转部位的定位一定要有卡具保证。另外还应设计一个量具，专门测量母线板到线圈环氧面某一可用作定位的表面的距离。该两个卡、量具应能有助于保证母线板位置的一致性。

4.2.3.2 Pressure test / 压力检测

After water fitting installation, the coil shall be sealed at one end and the cooling channel will be pressurized with water at 450 psi. There shall be no visible leak and change in pressure after one hour.

接好水接头后，封死线圈一端的水接头，对线圈进行450psi水压试验。一小时后，不应有可见漏水现象和压力泄漏。

4.2.3.3 Water Flow Test / 水流量测量

The water flow test shall be made for the finished coil. The test setup shall include:

- Means for measuring the inlet and outlet water pressures to an accuracy of ± 4.0 psi;
- Means for measuring the water flow to an accuracy of ± 5% of design value;
- Means for measuring the water temperature to an accuracy of ±2° C
- Means of adjusting the water flow rate.

With the water temperature in the range of 20° C to 25° C and with the water pressure between the inlet and outlet at 150 psi, the flow rate shall be measured. The flow rate under these conditions shall be at least 90% of the design value described in section 1.3. The technician name performing the test, the test date, pressure drop, water temperature and flow for the measured coil shall be recorded in the traveler for the tested coil.

完工线圈应进行水流量测量，其仪表设置应包括：

- 进、出水路设水压表，精确度为± 4.0psi；
- 流量剂表，精确度为设计值±5%美加仑/分钟；
- 水温测量表，精确度为±2° C；
- 水流量调整阀。

水流量测量时的水温应为20° 至25° C，进、出水压差为150psi。线圈在此条件下的水流量应至少为条款1.3所述设计值的90%。检验员姓名、日期、压力降、水温和水流量都应记入被测线圈跟踪卡。

4.3 Modulation System Coil Tests and Measurements / 调制线圈检测和测量