MQXB01 Fabrication Report

TD-02-027

Kerby, Nobrega, Bossert, Rife

1.0 Introduction

MQXB01 is the first production cold mass to be built in the LHCIR Quadrupole series. It was preceded by one prototype, P1 (described in TD-02-009). MQXB01 design is essentially the same as the prototype that preceded it, except that it does not include R & D related instrumentation, such as quench detection voltage taps, spot heaters, strain gauges to measure coil azimuthal preload, or instrumentation on the longitudinal preload screws (bullets).

Coil azimuthal size, MOE and preload target goals are listed in table 1.0.1. The coils are cured using a two-step cycle (to control interstrand resistance) with low pressure/high temperature followed by a high pressure/low temperature step. Strip heaters were manufactured by CERN, double element, with one transposition pitch of bare stainless steel alternating with one transposition pitch of copper coated stainless. The welded pack length was 38mm as in P1, with spaces between each pack to allow for radial cooling passages within the collared coil assembly. End plate thickness is 35mm.

The primary features of MQXB01 are listed below in Table 1.0.1. Changes from magnet P1 are highlighted in red and italicized.

Coil target sizes are identical to P1. The cable insulation system was adjusted slightly from P1 to compensate for actual measured coil sizes.

Inner Cable Strand No.	37
Inner Cable Strand Manufacturer	***Alsthom***
Inner Cable lay direction	Right Lay
Outer Cable Strand No.	46
Outer Cable Strand Manufacturer	Alsthom
Outer Cable lay direction	Left Lay
Cable Pre-baking	None
Strand Coating	None
Cable Cleaning Fluid	ABZOL VG
Inner Cable Insulation	25uM x 9.5mm ***w/ 58% overlap*** surrounded by 50uM x 9.5mm w/2mm gaps w/QIX
Outer Cable Insulation	25uM x 9.5mm ***w/ 50% overlap*** surrounded by 25uM x 9.5mm w/48% overlap w/QIX
Coil Curing temperature	190C/135C Two step cycle
Inner coil curing pressure	high at 135C/ low at 190C
Outer coil curing pressure	high at 135C/ low at 190C
Inner Coil target size	+300uM, (+.012)
Inner Coil target MOE	9GPa
Outer Coil target size	+250uM, (+.010)
Outer Coil target MOE	9GPa
Target Prestress	75-80 MPa
Coil end azimuthal Shim System	Shim ends to be same as body, tapering off toward end of saddle.
End Part Material	G-11CR
End Part Configuration	Iteration #2, 5 block design.
Splice Configuration	Internal

Voltage Tap Plan	***No Quench protection voltage taps. Taps on leads at ends (between quadrants) only.***
Inter layer strip heaters	None
Outer layer strip heaters	CERN version #2, double element, dwg. No. MD-369619.
Key extension	None
Inner coil Bearing Strips	None
Outer coil Bearing Strips	None
Collar configuration	38mm long solid welded packs, without bearing strips
Collar key configuration	152.4 mm long, phosphor bronze.
Strain Gauges	***No beam or capacitor gauges.***
Spot Heaters	***None***.
End Radial Support	Collet end clamps on both ends. Aluminum exterior cans with G-11CR quadrant pieces.
Collar/Yoke Interface	Radial clearance between collar and yoke.
Quadrant Lead Configuration	Double lead with superconducting cable for stabilizer
End longitudinal loading	Bullets apply load directly to coils, 8.9 kN (2000 lbs.) force per bullet. End cans are bolted to end plates longitudinally, preventing coils from contracting longitudinally.
Yoke Key Width	26.5mm
Strain Gauges on Skin	***None.***
End Plate Thickness	35mm
Tuning Shims	None
Other	Non-lead end keys mold released and replaced. Thermometers on end plates. Axial preload bolts not instrumented. Voltage taps on inner-outer coil splices (1/8 coil taps) are included, but will be used for testing only. See section 3.5.
Coil Fabrication Start Date	2/15/01
Cold Mass Completion Date	1/10/02

Table 1.0.1 MQXB01 features.

2.0 Superconducting Cable

2.1 Cable Mechanical Parameters

Tables 2.1.1 and 2.1.2 summarize the cable parameters used in MQXB01. There were no changes in the cable design parameters with respect to P1. Inner cable came from reel L-3-A-N0012, and was made by New England Electric Wire Corp. using Alsthom strand. Outer cable came from reel LHC-4-A-N0010, and was made by New England Electric Wire Corp. using Alsthom strand.

PARAMETER	UNIT	INNER CABLE FOR MQXB01	OUTER CABLE FOR MQXB01
Radial width, bare	mm	15.4	15.4
Minor edge, bare	mm	1.320	1.051
Major edge, bare	mm	1.610	1.241
Midthickness, bare	mm	1.465	1.146
Keystone angle,	deg	1.079	0.707
Pitch Length	mm	114	102
Number of strands		37	46
Lay direction		Right	Left

Table 2.1.1: *Cable design parameters for MQXB01.*

PARAMETER	UNIT	INNER CABLE FOR MQXB01	OUTER CABLE FOR MQXB01
Radial width, bare	mm	15.3855	15.4021
Minor edge, bare	mm	1.3214	1.0544
Major edge, bare	mm	1.6084	1.2374
Midthickness, bare	mm	1.4649	1.1459
Keystone angle,	deg	1.069	.681
Pitch Length	mm	114	102
Number of strands		37	46
Lay direction		Right	Left

Table 2.1.2: *Cable actual parameters for MQXB01.*

All cable was cleaned ultrasonically, at an elevated temperature, with ABZOL VG, in a degreaser made by Branson Inc. (the same machine used for the Tevatron). The degreaser is inserted into the cable insulating line, just before the cable is insulated.

2.2 Cable Electrical Parameters

Electrical Data and cable test data in sections 2.2 and 2.3 were taken at BNL. Two tests of inner cable and one test of outer cable were done. The ranges shown in the inner cable columns represent the range of values taken from the two tests.

PARAMETER	UNIT	INNER CABLE	OUTER CABLE
R(293 K)	μohms/cm	16.295-16.297	17.916
R(10 K)	μohms/cm	0.209-0.215	.348
RRR		76 - 78	51
C/Sc		1.30-1.30	2.05

Table 2.2.1: Cable electrical parameters as provided by BNL.

2.3 Cable Test Data

	INNER CABLE		OUTER CABLE	
B, T	I_c, KA	J_c, A/mm^2	I_c, KA	J_c, A/mm^2
6	20.637-21.193	2508-2574	11.797	2421
7	15.207-15.309	1848-1859	8.701	1786
8	9.425-9.778	1145-1888	5.606	1150

Table 2.3.1: Cable test data as provided by BNL

3.0 Coil Fabrication

3.1 Cable and Wedge Insulation

Table 3.1.1 summarizes the cable insulation parameters used in MQXB01. Note that the adhesive on the outer wrap of both inner and outer cable is modified polymide (QIX) instead of QI. QIX had been introduced late in the short magnet program. The wedges were insulated identically to their respective coils.

PARAMETER	INNER CABLE	OUTER CABLE
Number of wraps	2	2
Inner wrap:		
-material	Kapton tape 25 μm × 9.5 mm	Kapton tape 25 μm × 9.5 mm
-adhesive	None	None
-wrap structure	Spiral wrap with 58% overlap	Spiral wrap with 50 % overlap
Outer wrap:		
-material	Kapton tape 50 μm × 9.5 mm	Kapton tape 25 μm × 9.5 mm
-adhesive	Modified Polyimide (QIX)	Modified polyimide (QIX)
-wrap structure	Spiral wrap with 2 mm gaps	Spiral wrap with 48 % overlap

Table 3.1.1: **MQXB01 cable insulation parameters.**

3.2 Winding and Curing

Five inner and five outer coils were wound, cured and measured for MQXB01. Four inners and four outers were chosen, with the fifth coil left as a spare. All coils had wedge breaks staggered such that the breaks would not be coincident at any longitudinal location in the same coil. Gaps between the wedges before curing were 2.2mm.

3.3 Coil Measurements

3.3.1 Coil Straight Section

Coil azimuthal size and modulus measurements were taken over a range of pressures, 55 to 100 MPa. The design pressure for both the inner and outer coils at room temperature is about 75-80 MPa. Coils are measured with a 3 inch (76mm) gauge length along the straight section of the magnet, from Lead end to Non-lead end. During this process, resistance measurements are taken to ensure that there are no turn-to-turn shorts.

The target sizes are +300 μm for inner coils and +250 μm for outer coils, at a pressure of 83 MPa. These values represent a size "with respect to the design size inside the cross section when the magnet is operating". The larger sizes are necessary at room temperature to achieve the correct sizes when the magnet is cold and powered.

Table 3.3.1 lists the coils used in MQXB01 and their corresponding average size and modulus.

Coil Numbers	**SIDE A μm**	**E(A) GPa**	**SIDE B μm**	**E(B) GPa**
MQXBi-021	291	9.8	285	9.7
MQXBi-022	324	10.6	323	10.1
MQXBi-023	299	10.4	300	10.2
MQXBi-024	307	10.2	301	10.1
MQXBo-019	212	10.1	226	10.7
MQXBo-020	237	10.8	246	10.0
MQXBo-021	205	9.2	206	9.4
MQXBo-022	191	10.2	204	11.0

Table 3.3.1: **MQXB01 coil body size and modulus.**

Variation of the size along the length of the coils is shown in Figs 3.3.1 and 3.3.2. Side A is the "first wound" side of the coil and Side B is the side with the lead extending from the end of the saddle. The full length of each coil is measured, encompassing 67 positions, each 76mm long.

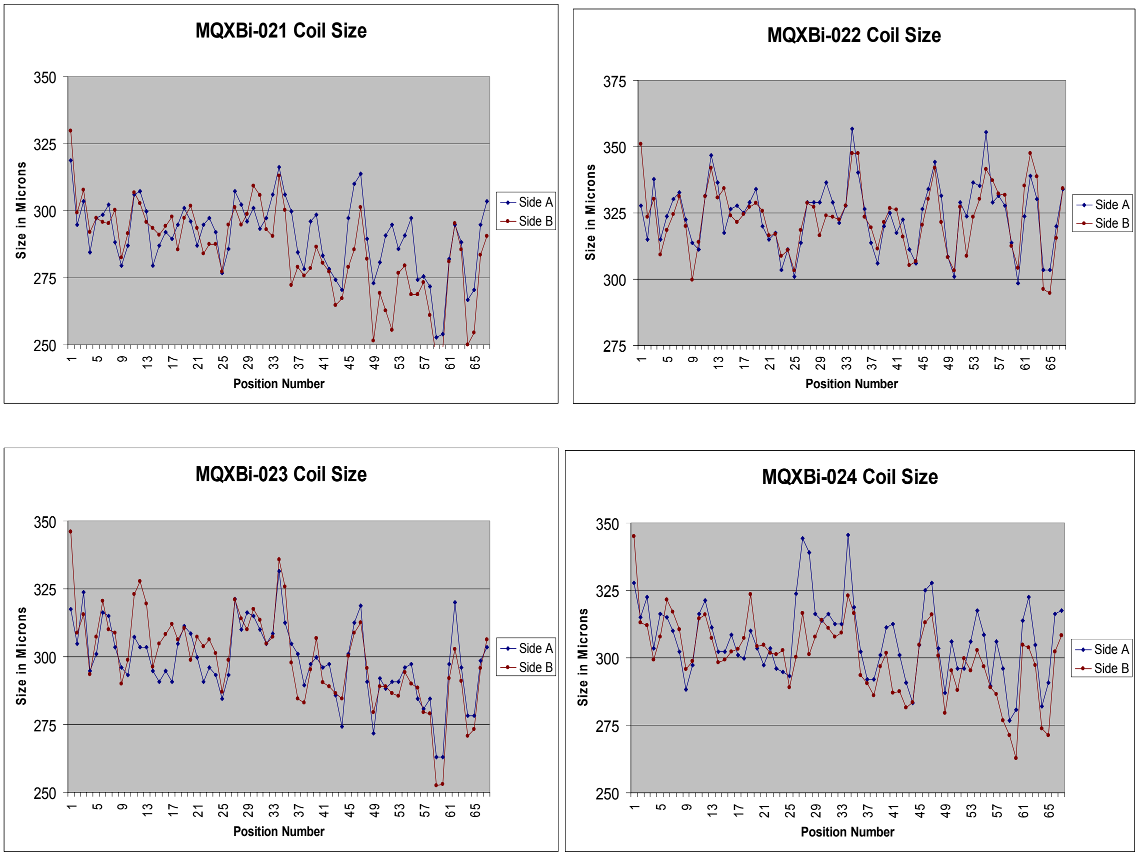


Figure 3.3.1: Variation of size along the length of inner coils.

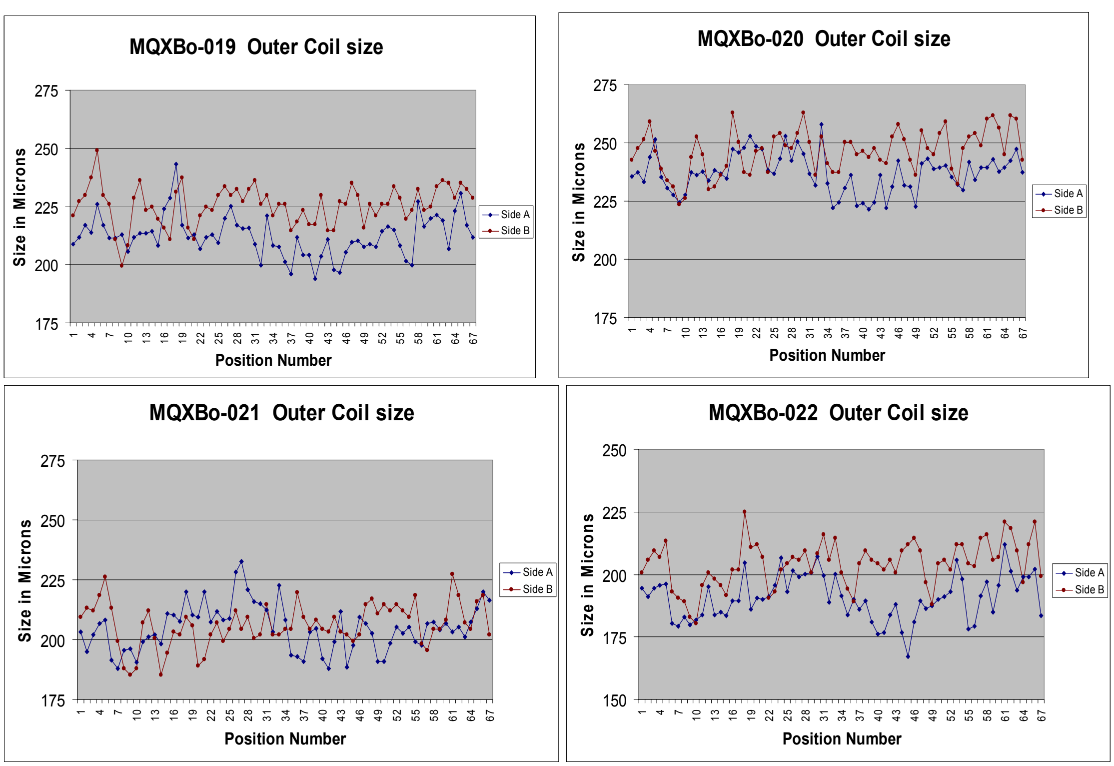


Figure 3.3.2: Variation of size along the length of outer coils.

3.4 Coil Shimming

3.4.1 Coil Straight Section

If the magnet coil sizes do not meet the target, they may be azimutally shimmed with kapton to reach the target levels. The target pre-stress for MQXB01 is about 75-80 MPa. This corresponds to a nominal coil size of +300 µm for inner coils and +250 µm outer coils. The inner coil size in MQXB01 varied from 285 to 324 µm with an average of 304 µm; whereas the outer coil size varied between 191 and 246 µm with an average of 216 µm. The following table lists the coil and shim sizes used in MQXB01 (in the case of MQXB01, no shims were used):

I/O	Quadrant	Coil #	Coil Size µm	Pole Shim µm	PP Shim µm	Target µm	Shimmed Coil Size µm
Inner	1A	i-021	291	0	0	300	291
Inner	1B	i-021	285	0	0	300	285
Inner	2A	i-022	324	0	0	300	324
Inner	2B	i-022	323	0	0	300	323
Inner	3A	i-023	299	0	0	300	299
Inner	3B	i-023	300	0	0	300	300
Inner	4A	i-024	307	0	0	300	307
Inner	4B	i-024	301	0	0	300	301
Outer	1A	o-019	212	0	0	250	212
Outer	1B	o-019	226	0	0	250	226
Outer	2A	o-022	191	0	0	250	191
Outer	2B	o-022	204	0	0	250	204
Outer	3A	o-020	237	0	0	250	237
Outer	3B	o-020	246	0	0	250	246
Outer	4A	o-021	205	0	0	250	205
Outer	4B	o-021	206	0	0	250	206

Table 3.4.1: *Kapton shimming used in the coil straight section.*

3.4.2 Coil Ends

Resistance readings were taken while compressing the ends of the MQXB01 coils to 83 MPa, both lead and non-lead end of both inner and outer coils. Size measurements were not taken on the ends. The ends of the MQXB01 coils were shimmed azimuthally according to a formula that was established on the last short models (HGQ07-9). Long production coils are all shimmed according to the same formula. Shimming is shown in Figure 3.4.1 and is recorded in FNAL drawings 5520-MD-369695 and 5520-MD-369696.

After installing the shims on MQXB01, one layer (.005 inches or 125 microns) of kapton were removed for a distance of 1/2 inch (1.3 cm.) at the back end of each saddle. This was done in an attempt to alleviate high stresses near the end of the end can, which were not seen on short magnets. (See also Section 6.1 and Figure 6.2.1). After the end cans were installed, the back surfaces of the saddles were observed to be deforming slightly (bulging in the center), presumably due to the uneven pressure at the ends of the saddle (see DR 0270). Beginning with MQXB02, these shims will not be removed. Dimensions in Figure 3.4.1 are in mm.

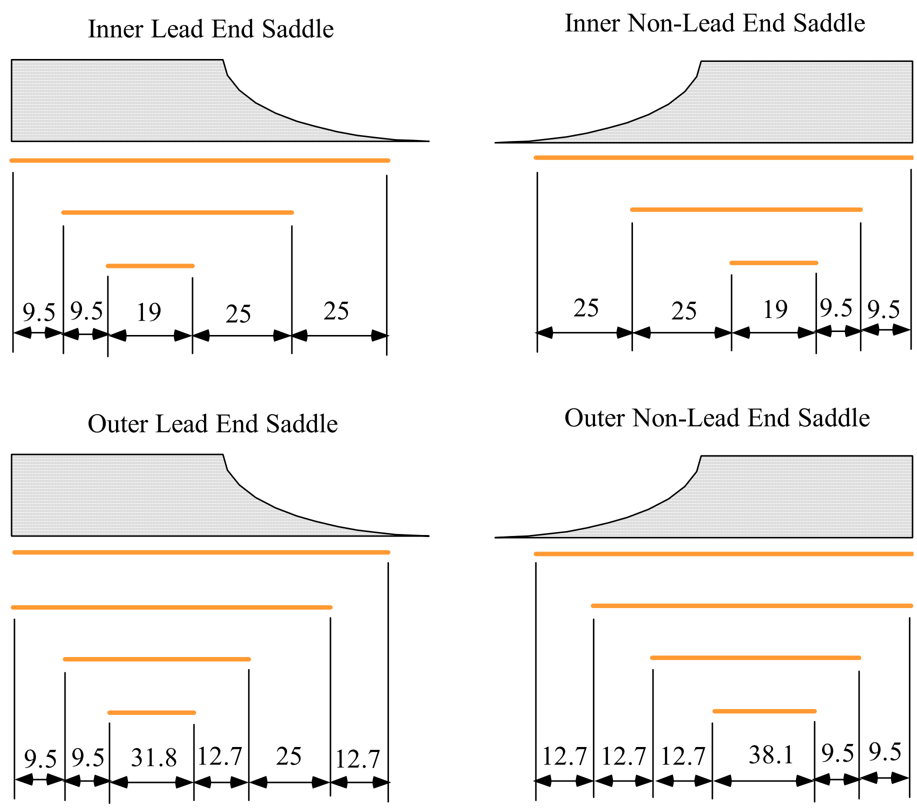


Figure 3.4.1: End-Shimming on MQXB01

3.5 Voltage Taps

Quench characterization voltage taps and spot heaters were not used on MQXB01, and will not be used on any MQXB production magnets. Since MQXB01 is part of the first Q2 to be tested at Fermilab, 1/8 coil taps (located on the inner-outer layer splices) are included for readout during testing only. The wires from these taps will be terminated after testing and consequently will not be included in the instrumentation connector when the magnet is shipped to CERN. They are used on MQXB01 and MQXB02 only, and will be discontinued after MQXB02.

4.0 Coil Assembly

4.1 Coil Arrangement

Coils in LHCIR Quadrupole magnets are arranged to obtain the most uniform possible preload distribution between quadrants, given the coils available. The coil arrangement is shown in Figure 4.1.1. The amount of shim placed at each pole and parting plane is shown in red (positive numbers indicate kapton added, negative numbers indicate kapton removed). Shims may be added to (or removed from) the parting plane and/or pole area to achieve the "target" azimuthal coil size and hence the desired preload. See also section 3.4 for a discussion of coil shimming. The numbers in light blue in Figure 4.1.1 shown near each midplane (e.g., 304.5i, 208o, for Q1/2) show the "after arrangement and shimming" sizes of the inner and outer "octant pairs", respectively, in microns.

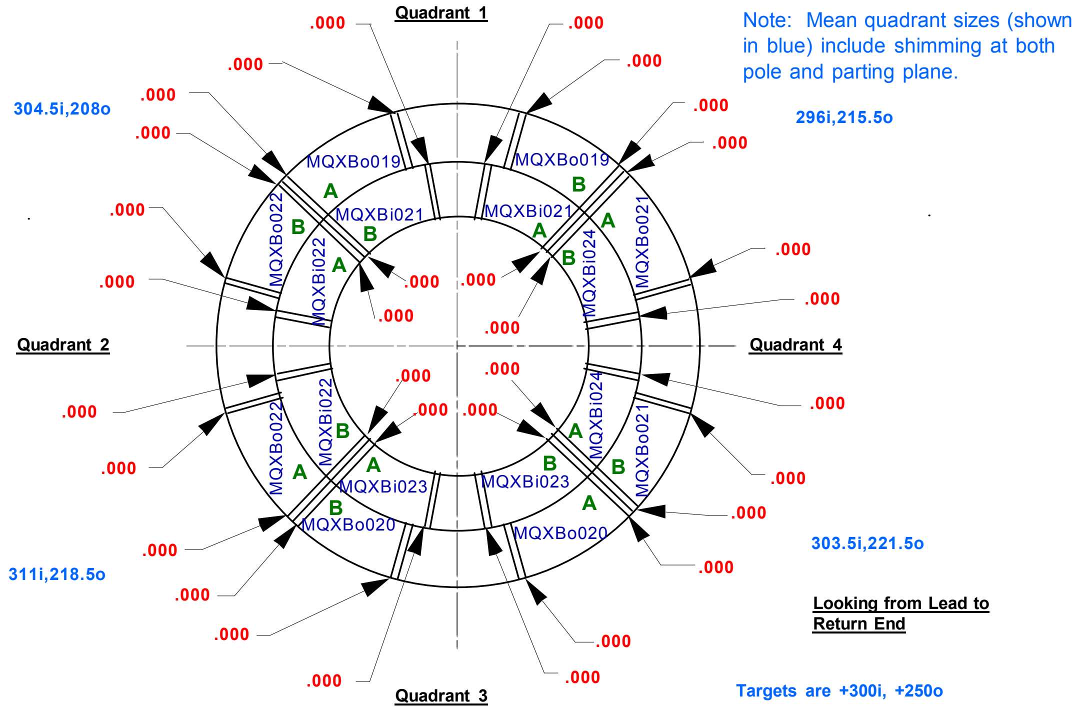


Figure 4.1.1 MQXB01 Coil Arrangement

4.2 Splices

The pole turn of each inner/outer coil pair needs to be spliced together. Splices are 114 mm long, slightly greater than the cable transposition pitch. Areas to be spliced are preformed, and filled with solder before the coil is wound. The filled, or "tinned" sections are then spliced after the coils are assembled on the mandrel. The MQXB01 splices were made at 280 degrees C with 70% lead 30% tin solder, using a Kester 1544 flux. (Beginning with magnet MQXB04, the solder/flux combination changes to 96% tin 4% silver with Kester 135 flux.)

All splices were insulated with two layers of Kapton tape, one layer of 25um thick × 9.5 mm wide surrounded by one layer of 50um thick × 9.5 mm wide. Both layers are spiral wrapped with 2 mm gaps. The second layer is wrapped directly on top of the first layer, leaving uncovered bare cable in the 2mm gaps. Axial and radial cooling channels were made in the G11CR spacers, which surround the splice as well.

4.3 Ground Wrap System

The coil insulation and ground wrap system in the body for MQXB01 is shown in Figure 4.3.1. A complete description of the ground wrap system for MQXB01, including body and ends, is shown in assembly drawing #5520-MC-369659. All layers of kapton are .005 inch (125um) thick unless otherwise specified in the figure.

Quench protection heaters are placed radially between the outer coil and collar laminations. The heaters have stainless steel elements, .001 inch (25um) thick, .630 inches (16mm) wide, copper plated on one side. The copper is etched away intermittently over 4.00 inch (101.6mm) lengths, exposing the stainless, with 4.00 inch (101.6mm) lengths of copper plated areas between them. The stainless/copper element is sandwiched between (and bonded to) two pieces of .004 in. (100 micron) thick kapton. They are described in detail in drawing #5520-MB-369369.

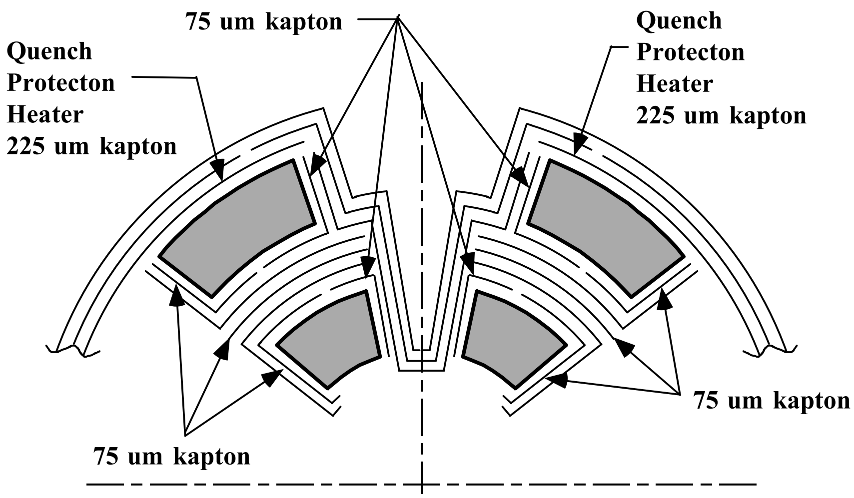


Figure 4.3.1 MQXB01 Body Coil and Ground Insulation System

5.0 Collaring and Keying

5.1 Collaring

To ensure that the splices are aligned properly, the coils are assembled so that the back end of the lead end keys of all four quadrants in both layers are coplanar. The back ends of the outer coil keys on the lead end are then "cut to fit" to allow the back of all four quadrant keys to be coplanar. On the non-lead end, the outer coil keys are cured into the coils. Their back surface defines the coil length after springback. The inner coil keys are cut to fit at assembly to make them coplanar (quadrant-to-quadrant variations in length created by differences in outer coil springback are small enough to ignore).

Collars are welded into packs, each 38mm long, with "large" and "small" alternating laminations, and shown in Figure 5.1.1. Collar laminations are made of a geometry which does not include bearing strips. Each collar pack is 25 laminations long, (~39 mm total length). Packs are made with a “large” lamination on each end, creating a gap between each collar pack in each quadrant, where a “small” lamination is missing. These gaps allow passage for heat flow.

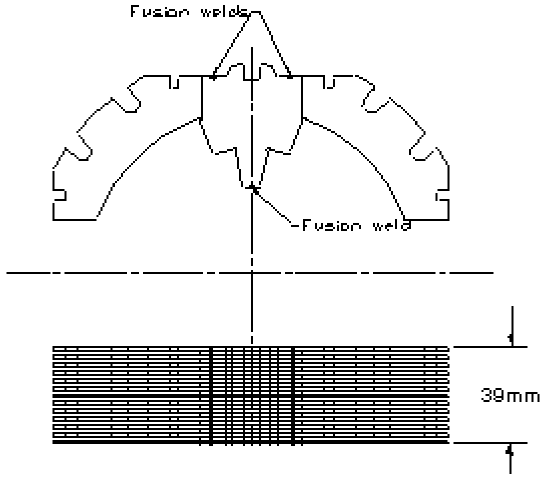


Figure 5.1.1: Collar pack.

MQXB01 does not include beam gauge packs or two capacitor gauge packs to measure coil preload. No production magnets include this instrumentation.

5.2 Keying

MQXB01 was keyed according to procedure #TD-02-010. Collaring keys were 6 inches long. Cylinder pressures were increased slightly from the procedure to fully seat the keys. Steps (including press pressures used on MQXB01) are shown below:

1) Massage at 900 pump psi main cylinder pressure
2) Massage at 1800 pump psi main cylinder pressure
3) Partial key insertion with main cylinder pressure 3000 pump psi/key cylinder pressure 700 pump psi
4) Full key insertion pass with main cylinder pressure increased to 4700 pump psi and key cylinder pressure increased to 3300 pump psi
5) 2nd full key insertion pass with main cylinder pressure increased to 5000 pump psi and key cylinder pressure increased to 3600 pump psi
6) Final pass straddling keys at 5000 pump psi main cylinder pressure and 4000 pump psi key cylinder pressure.

After keying, a ground short was discovered (described in detail in section 9.0). 12 inches (30cm) of collars were removed at the lead end to repair the short. These packs were replaced and rekeyed in a similar process, but without the assembly mandrel.

5.3 Mechanical measurements

The outside collar diameter measurement data for the collared coil assembly is shown in Figures 5.3.2-5.3.3. The measurements are taken from the non-lead end to the lead end of the collared area (back of key to back of key as shown in Figure 5.3.1), approximately every 8 cm (three inches). Diameters are displayed in the figures in mm.

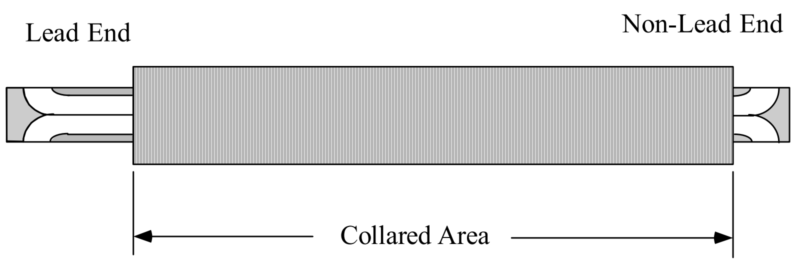


Figure 5.3.1: Collared coil assembly without end clamps installed.

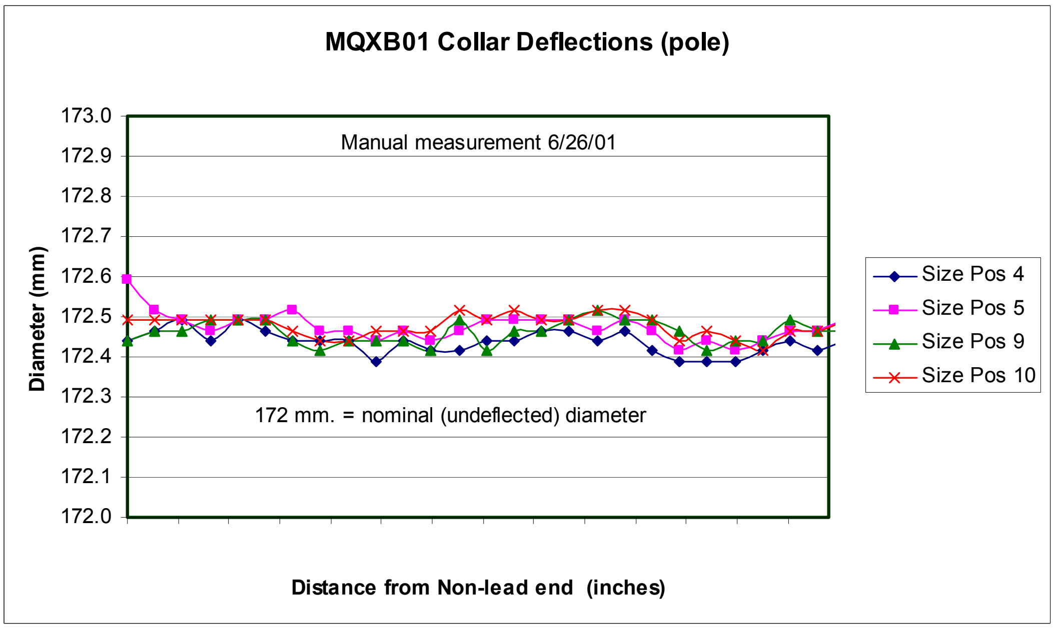


Figure 5.3.2: Collared coil deflections at pole region after keying.

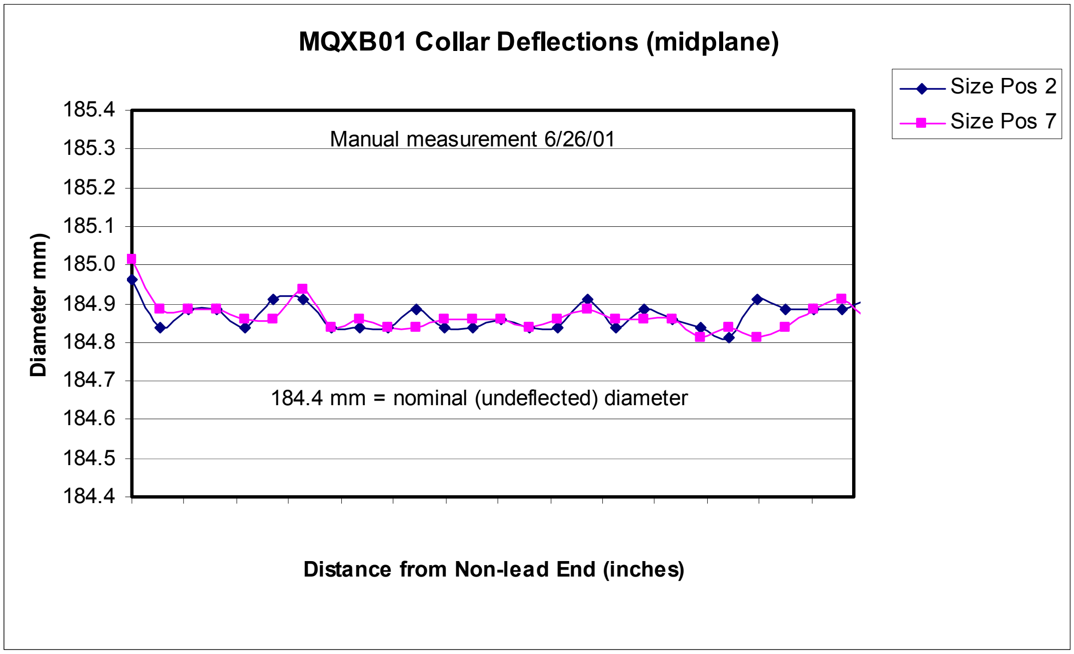


Figure 5.3.3: Collared coil deflections at midplane region after keying.

The measurements show a mean radial deflection of 228 um at the midplane and 226 um at the pole. When adjusted for actual collar lamination sizes (the plots in Figures 5.3.2 and 5.3.3, above, do not reflect these adjustments), these deflections are similar to that of the last two short models, HGQ08 and HGQ09 and P1, as shown in Table 5.3.1 and Figure 5.3.4, indicating a similar preload.

	Adjusted		Unadjusted	
Magnet No.	Midplane	Pole	Midplane	Pole
HGQ08	222	237	165	180
HGQ09	154	159	115	120
P1	197	202	249	254
MQXB01	176	174	228	226

Table 5.3.1: Collared coil deflections of HGQ08-MQXB01.

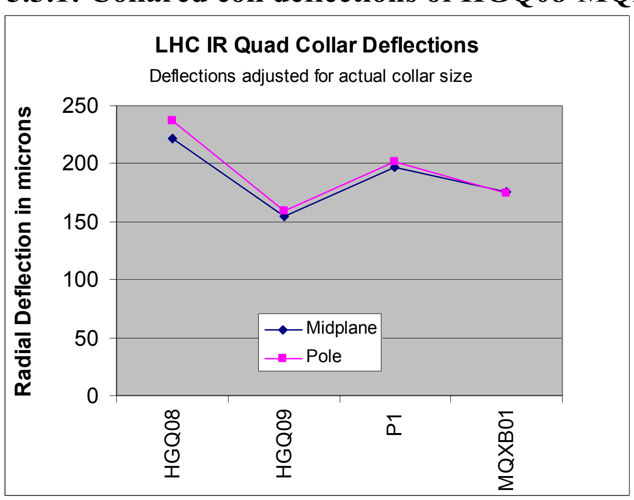


Figure 5.3.4: Collared coil deflections of HGQ08-MQXB01.

After keying is complete, the magnet body is measured longitudinally, and the center of the magnetic length is marked on the collar surface. This mark will be transferred to the skin surface during the yoking process.

6.0 End Clamps

6.1 Installation Procedure:

The lead end clamp on P1 is 249.8mm (9.833 inches) long and the non-lead end clamp is 131.9mm (5.194 inches) long. G-11 filler cones were used. Longitudinal force required to close the "collet' end clamps were 384 kN (86400 lbs.) on the lead end and 149 kN (33600 lbs.) on the non-lead end.

6.2 Measurements and Shimming:

Based on measurements of short models and P1 (the full size prototype), it was decided to increase the thickness of radial ground insulation surrounding the outer coil ends by 75 microns (on the radius) at both ends from the original design (see the P1 Fabrication report, TD-02-009, for more details). The deflection of the diameter of the aluminum end cans according to pi-tape measurements (with the extra 75 microns of insulation included) are shown below in Figure 6.2.1 (target diameter change from FEA, was 250 - 300 microns at the LE and 200-250 microns at the non-LE).

The diameter, on short models, typically decreased on both lead and non-lead ends as the distance from the magnet body increased. On the long magnets (both P1 and MQXB01), the diameter decreased on the non-lead end, as did the short models, but, unlike the short models, the diameter increased slightly as distance from the body increased on the lead end. This is probably attributable to the lead stabilizer, which is soldered to the coil lead over the last 2 cm. each coil as it exits the end. Soft copper-only cable was used as stabilizer on the short models, while harder superconducting cable is used on long magnets.

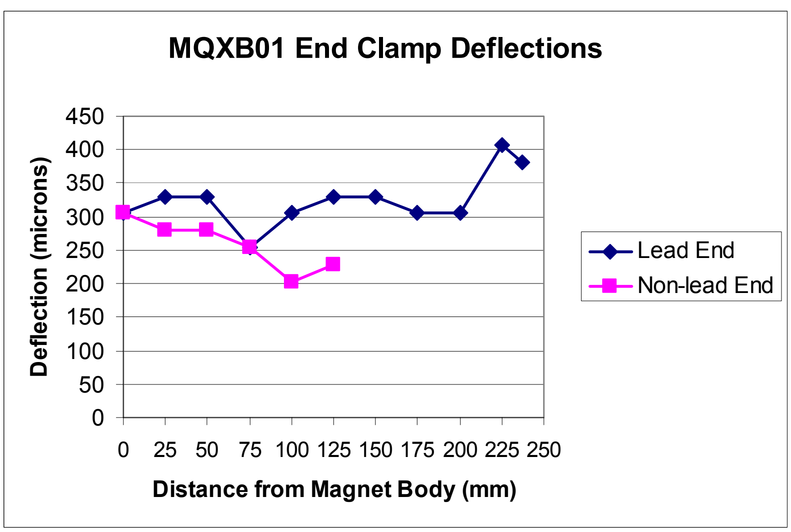


Figure 6.2.1: Aluminum End Can Radial Deflection

7.0 Yoke and Skinning

7.1 Assembly Configuration:

All yoke lamination packs were fusion welded longitudinally in 7 places (5 welds on outer surface and 2 welds on inner surface). 9 stainless steel laminations were welded to the lead end side of the straight section yoke, and 16 on the non-lead end. Stainless steel modified yoke laminations were used for lead and non-lead end to cover the end cans. Figure 7.1.1 shows the design length and the layout of the yoke laminations during assembly. Actual length between end cans was 5222mm, 9mm shorter than the design, primarily due to coil shrinkage after curing. The actual total coil length is therefore also shorter than the design by the same amount.

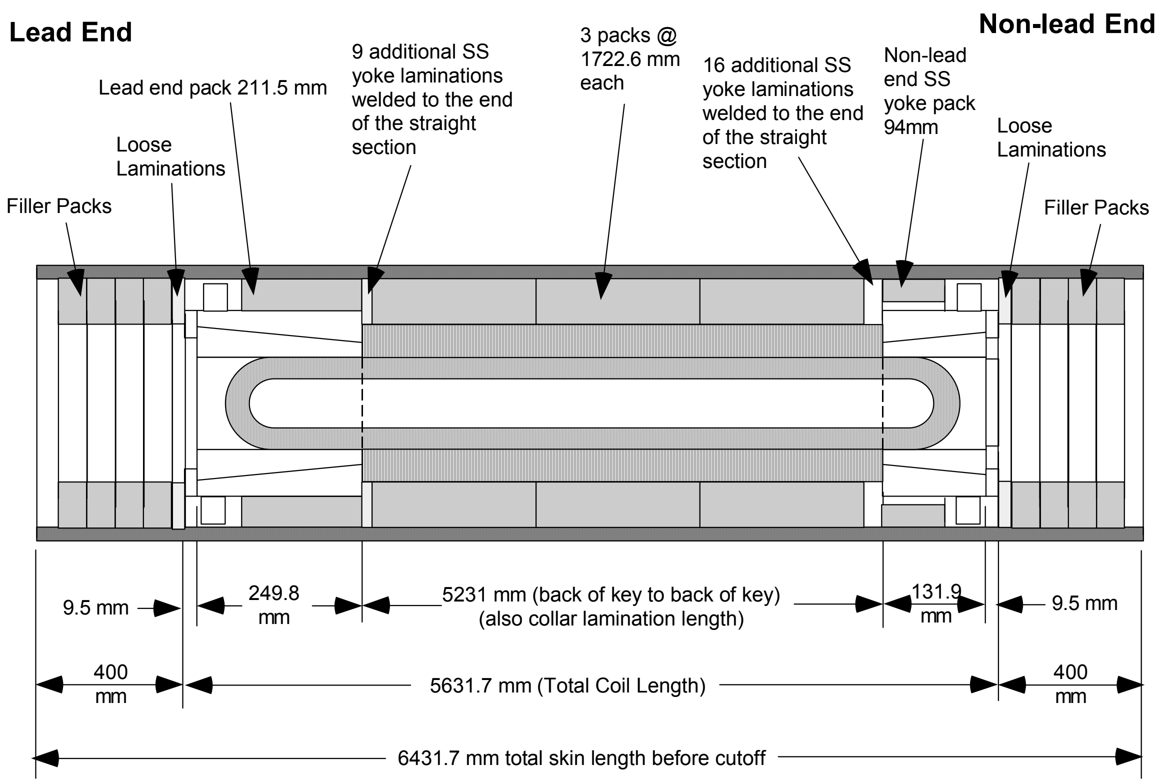


Figure 7.1.1: MQXB01 Yoke Assembly Configuration Before Welding

7.2 Welding:

The skin alignment key was 26.5 mm wide for MQXB01, as was Pl. The 26.5-mm wide skin alignment key leaves a gap of 3mm (.12 in.) between the upper yoke and the upper skin; also a 3mm (.12 in.) gap between the lower yoke pack and skin alignment key. The total gap allowed for weld shrinkage is 6mm (.24 in.).

The magnet was compressed in the contact tooling with a hydraulic press pump pressure of 4MPa (600 PSI) during welding, corresponding to a force of about 23700 kg/meter (16000 lbs./ft) of magnet length. A pressure above 3.3MPa (500 PSI) must be applied to completely collapse the springs in the wheel units of the bottom tooling. The first pass was a fusion pass. Then, consecutively, four filler passes were applied. After welding, the skin was cut to the precise length, and the end plates were welded.

7.3 Outside Diameter Measurements:

Skin outside diameter measurements were taken at different angles after welding the end plates, at the angles shown in Figure 7.3.1. Data and plots are shown in Table 7.3.1 and Figure 7.3.2 (values in mm).

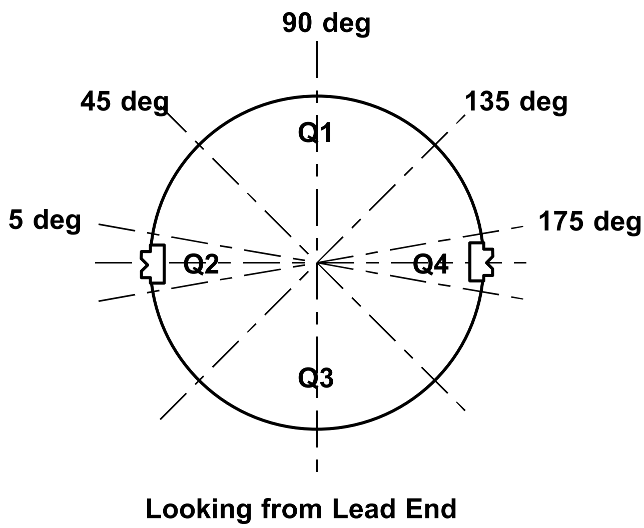


Figure 7.3.1: Yoke Outside Diameter Measurement Positions

Distance from LE (in.)	Distance from LE (meters)	5 deg.	45 deg	90 deg	135 deg	175 deg
0	0.0	419.2	415.7	414.9	415.6	418.8
50	1.3	416.7	416.5	416.6	416.7	416.8
100	2.5	416.7	416.6	416.8	416.8	416.6
150	3.8	416.7	416.7	416.7	416.7	416.6
200	5.1	416.5	416.5	416.8	416.8	416.7
240	6.1	418.1	416.3	415.6	415.9	418.5

Table 7.3.1: MQXB01 yoke outer diameter according to micrometer measurements taken at different angular positions between skin alignment keys

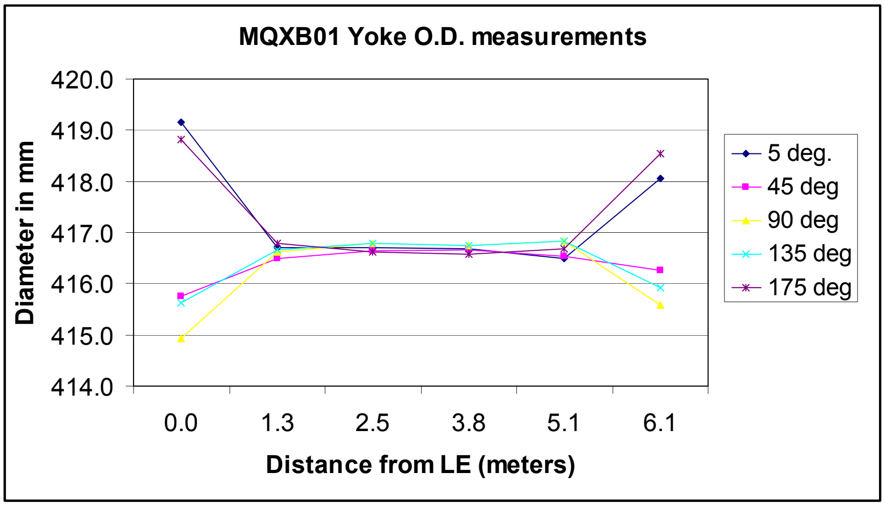


Figure 7.3.2: Yoke Outer Diameter Measurements Plotted

7.4 Twist Measurements:

The twist in the cold-mass assembly after welding the skin and the end plates was measured on a granite table with a level and is shown in Figure 7.4.1. The twist was measured to be 0.18 milli-radians per meter in the straight section of the magnet (rms). The allowed twist for the MQXB Cold Mass is less than 0.2 milli-radians per meter. Peak-to-peak variations in the measurements were 1.2 milli-radians.

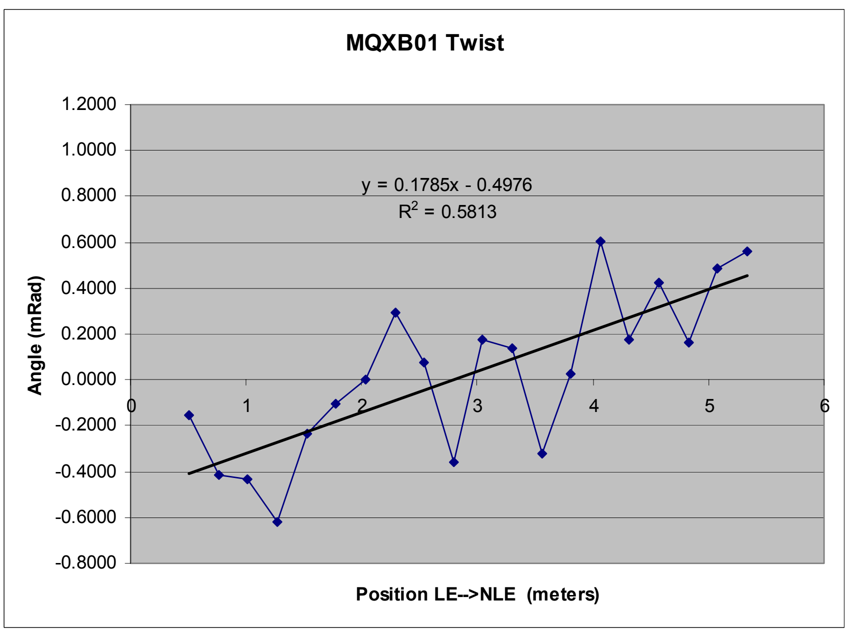


Fig 7.4.1: MQXB01 Cold Mass Assembly Twist Measurements

7.5 Straightness Measurements

Straightness of the yoke in both the vertical and horizontal axis are taken by measuring the distance between the skin surface and a stretched wire. They are described in Figure 7.5.1 and shown for MQXB01 below in Table 7.5.1.

The wire is stretched across the length of the skin, touching on each end. Measurements are taken from the wire to the skin. Positive numbers, therefore, in Table 7.5.1 represent concavity on the surface noted. A straight or convex condition will result in zero readings.

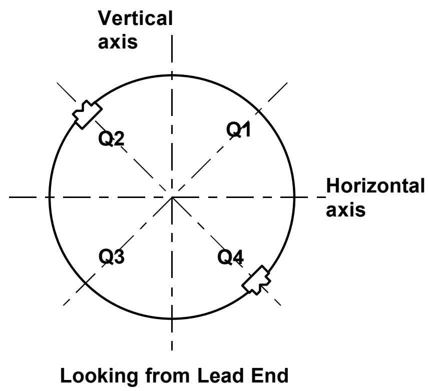


Figure 7.5.1: Straightness Measurement Positions

Distance from Lead End Plate (meters)	Vertical Measurement top (microns)	Vertical Measurement bottom (microns)	Horizontal Measurement left (microns)	Horizontal Measurement right (microns)
LE Plate	0	0	0	0
0.3	0	0	0	25
0.6	0	0	0	0
0.9	0	100	0	0
1.2	0	100	0	100
1.5	0	125	0	50
1.8	0	100	0	50
2.1	0	150	0	75
2.4	0	125	0	100
2.7	0	125	0	150
3.1	0	100	0	125
3.4	25	0	0	100
3.7	25	0	0	125
4.0	0	0	0	125
4.3	0	0	0	175
4.6	0	0	0	75
4.9	0	0	0	0
5.2	0	0	0	0
5.5	0	0	0	0
NLE Plate	0	0	0	0

Table 7.5.1: Straightness Measurements

7.6 Axial Loading (Bullets & Bolts):

The axial support system of the magnet is shown below in Figure 7.6.1:

The end load is applied by hand tightening the bullets to the bullet preload plate, then tightening the axial preload bolts to the specified amount. Strain gauges to read longitudinal load were not used on MQXB01, and will not be used on any production magnets. Torque applied to bullets was established from strain gauge readings of short models and P1. The complete bullet tightening procedure is explained in FNAL document # 5520-ES-369708, Bullet Torque Specification for LHCIR Quad MQXB Prototypes.

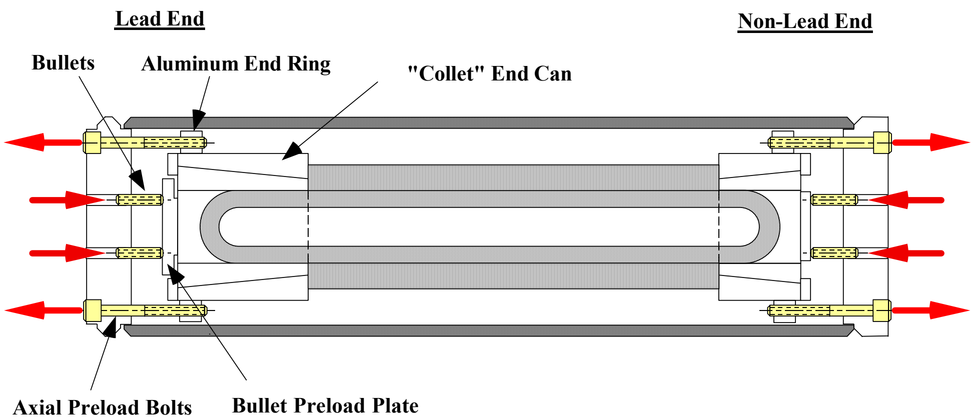


Figure 7.6.1: Axial Support of the Cold Mass Assembly

Each of the four bolts are tightened with a torque wrench, to 1200 inch-lbs. With that torque, each bolt applies 35.6 kN (8,000-lbs.) tension load to the magnet. As a result of the loading of the magnet with bolts, the bullets are subjected to a compressive load of 8.9 kN (2,000 lbs.) each. The total force applied to the magnet is therefore 107 kN (24,000-lbs.) tension.

8.0 Final Assembly

8.1 Final Electrical Measurements

MQXB01 was hi-potted coil to ground, heaters to ground and heaters to coil at 5000 V. Coils were hipotted across parting planes at 3000V. Leakage in all cases is required to be less than 3 μA. All tests were successful. Hipot leakage values are shown in Table 8.1.1.

Hipot	Result
Coil to Ground	248nA at 5000V
Strip heaters to Coil & Ground	150nA at 5000V
Coils Q1 to Coils Q2 across midplane	50nA at 3000V
Coils Q2 to Coils Q3 across midplane	50nA at 3000V
Coils Q3 to Coils Q4 across midplane	50nA at 3000V
Coils Q4 to Coils Q1 across midplane	50nA at 3000V

Table 8.1.1. MQXB01 Hipotting Data

Final electrical data is shown in Table 8.1.2:

	Resistance ohms	**Ls M H**	**Q**
Q1 - inner	.2557	546.71	1.06
Q1 - outer	.3182	883.328	1.36
Q2 - inner	.2546	554.993	1.05
Q2 - outer	.3184	879.619	1.36
Q3 - inner	.2563	542.812	1.05
Q3 - outer	.3189	875.682	1.36
Q4 - inner	.2549	544.786	1.05
Q4 - outer	.3182	878.629	1.35
Q1 – Quadrant total	.5717	2.3661	1.99
Q2 – Quadrant total	.5722	2.3291	1.99
Q3 – Quadrant total	.5730	2.3161	1.98
Q4 – Quadrant total	.5728	2.3233	1.97
	Resistance ohms	**Ls MH**	**Q**
Magnet Total	2.292	13.4704	5.01

Table 8.1.2: Magnet Resistance, L and Q measurements.

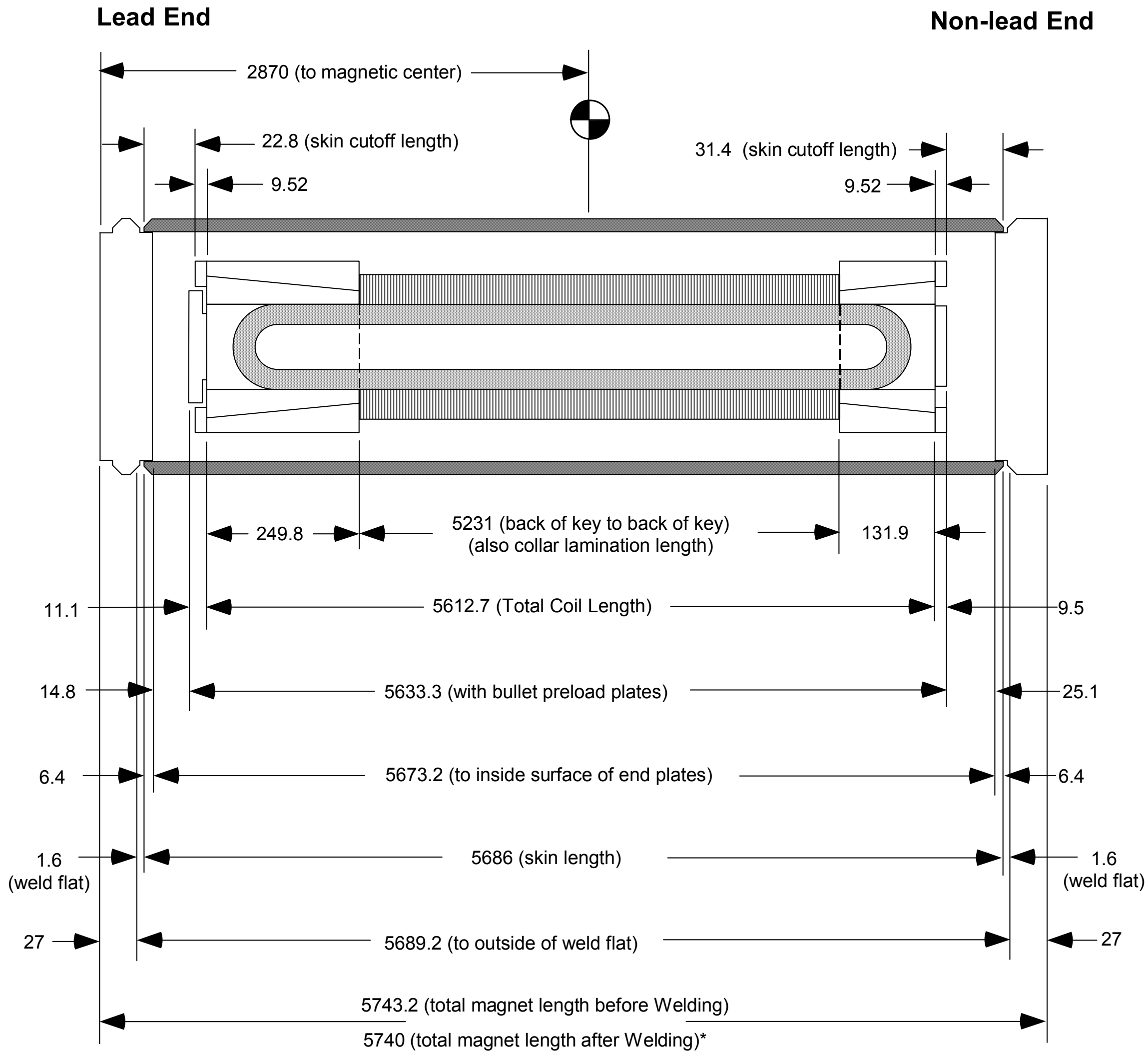
Heater resistances are shown in Table 8.1.3:

Strip Heater	**Resistance ohm**
Circuit A	
Circuit B	

Table 8.1.3: Heater resistance measurements

8.2 Mechanical Measurements

Design and actual finished longitudinal dimensions of the MQXB01 cold mass are shown in Figures 8.2.1 and 8.2.2. Figure 8.2.2 shows the longitudinal position of the magnetic center, from the measurements taken in Section 5.3.



*Note: both 1.6mm weld flats close to zero after welding end plates, decreasing the overall length by 3.2mm.

Figure 8.2.1: Design Dimensions of MQXB01

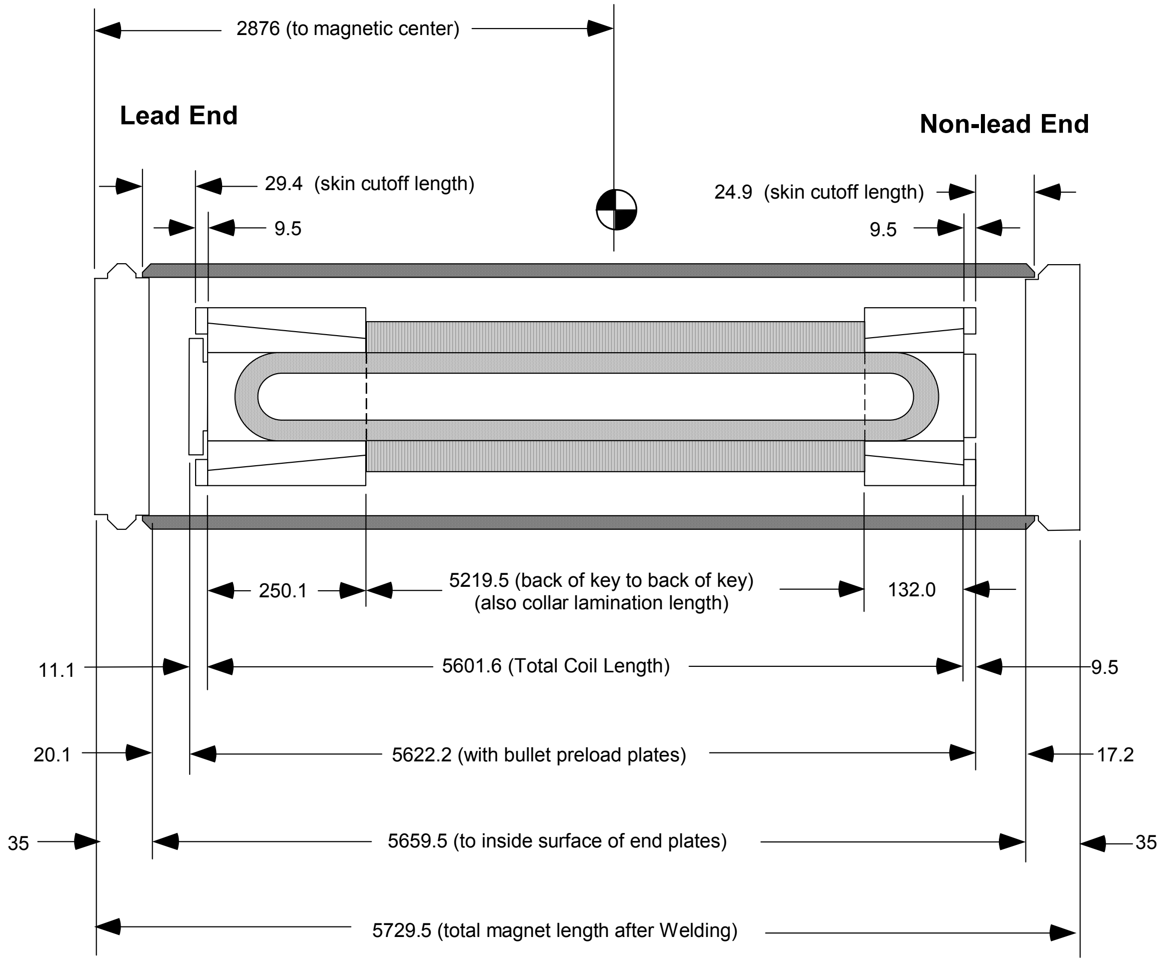
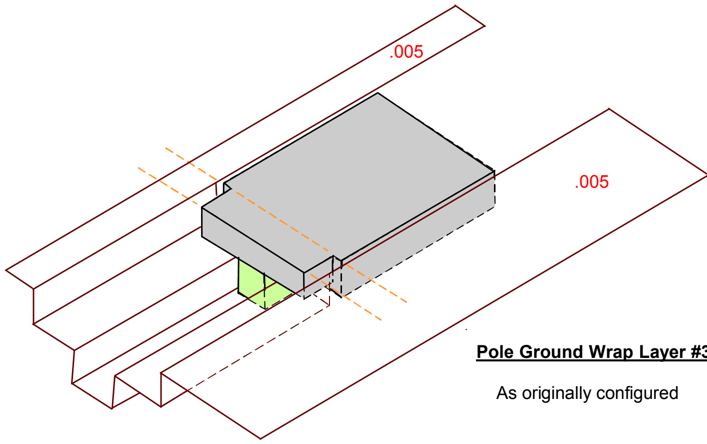


Figure 8.2.2: As-built Measured Dimensions of MQXB01

9.0 Discrepancies and Comments

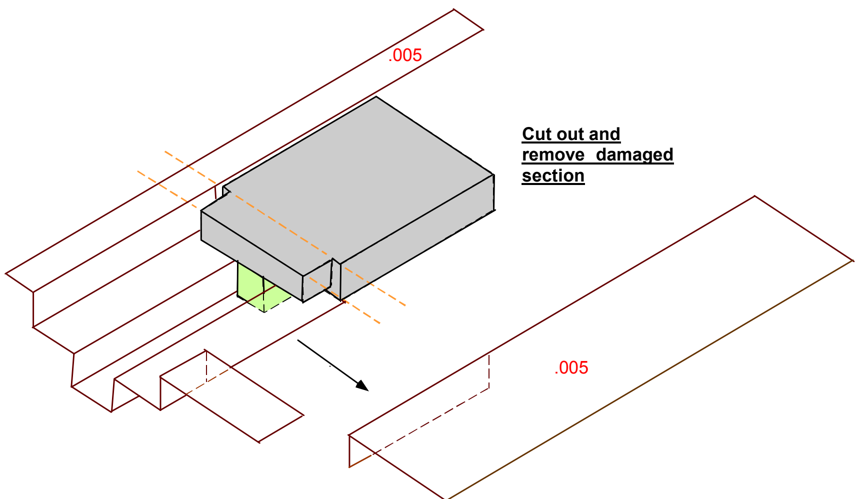
There were several hipot failures during the construction of MQXB01. They are listed below.

4) Q2 coils to ground at 3.5 KV. Found to be the 2nd collar lamination from the lead end, cutting through the ground wrap, and contacting the coil on the outer coil pole turn. Solution was to remove the last 12 inches of collar laminations at the lead end, patch the ground wrap, and re-collar and key the magnet, leaving out the last three laminations from the lead end. To fill the space, a plastic "key extension", 3 laminations thick, was inserted into the pole in the pole area of inner and outer coils, and the end clamp was installed longitudinally three lamination thicknesses toward the body of the magnet. This was done to move the high stress point, where the laminations end, to a different position. Recorded in DR 0233 and DR 0236 and described in Figure 9.0.1 below (dimensions in Figure 9.0.1 are in inches).

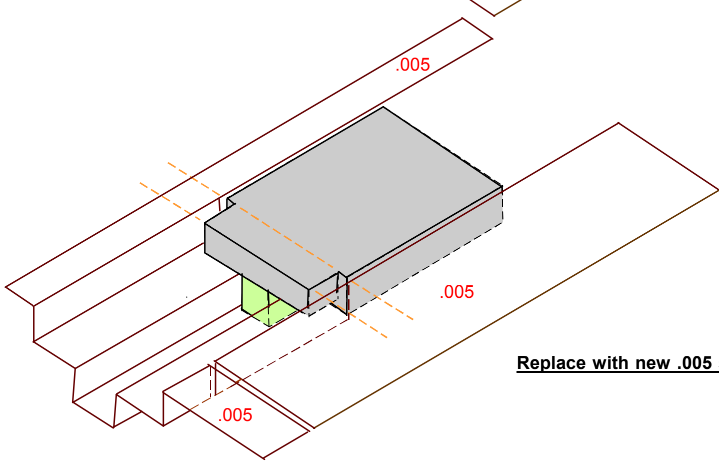


Pole Ground Wrap Layer #3, Outer coil quadrant 2

As originally configured



Cut out and remove damaged section



Replace with new .005 section

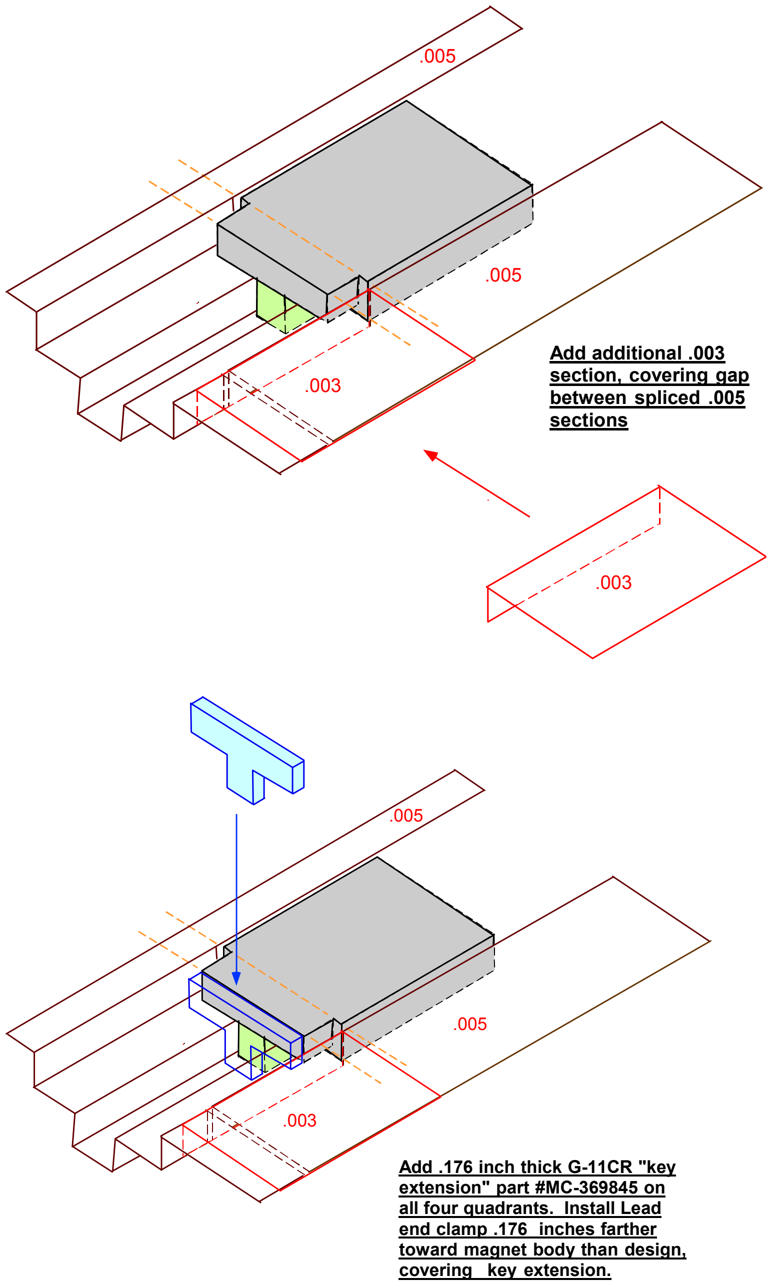


Figure 9.0.1: Ground Wrap Repair

Long term solution was to:

a) Round out the edge on the last collar lamination, where the lamination contacts the coils. This was supposed to have been done as a solution to a similar short on the previous magnet, but was overlooked.
b) Add more holes to the assembly mandrel near the end, allowing more support pieces and resulting in better ground wrap placement on the ends before collaring. More holes were added to the body as a solution from the previous similar short, but the last, most critical holes in the last 12 inches at each end had not been done.

5) Heater-to-ground short after welding end plates. Heater wire was contacting preload plate. End plate was removed, and wire was repaired. End plate then reinstalled. The long term solution is to run heater wires out with leads as was done on the short models and P1, instead of through a hole in the preload plate. Recorded in DR 0268.

Whenever an anomalous situation occurs during the construction of a magnet, a discrepancy report is filed. All discrepancy reports filed during the construction of the MQXB01 cold mass are listed in Table 9.0.1. Complete reports, with their dispositions and corrective actions, can be obtained from the FNAL Technical Division Process Engineering Department.

DR No	Discrepancy Description
HGQ-0169	THE INNER WEDGE MC-369693 USES 220 WEDGE INSTEAD OF PRECUT WEDGE
HGQ-0168	THE INNER WEDGE MC- 369393 USES 220 WEDGE INSEAD OF PERCUT WEDGE
HGQ-0164	THE OUTER WEDGE ASSEMBLY MC-369692 USES A 220 WEDGE INSTEAD OF PRECUT WEDGES
HGQ-0184	Cable for this coil had been previously insulated to the insulation scheme detailed in the traveler. Due to the cured inner coil size change the cable will be stripped on insulation and re-insulated to a new scheme.
HGQ-0188	The wedges for this assembly had been previously insulated to the scheme detailed in the traveler. Due to an insulation scheme change the wedges will be stripped of insulation and re-insulated to a new scheme.
HGQ-0187	The wedges for this assembly had been previously insulated to the scheme detailed in the traveler. Due to an insulation scheme change the wedges will be stripped of insulation and re-insulated to a new scheme.
HGQ-0185	The preform on this insulated unit length of cable will be cut off and re-made after cable is re-insulated to new insulation scheme.
HGQ-0183	Cable for this coil had been previously insulated to the insulation scheme detailed in the traveler. Due to the cured inner coil size change the cable will be stripped of insulation and re-insulated to a new scheme.
HGQ-0186	The preform on the insulated unit length of cable will be cut off and re-made after cable is re-insulated to new insulation scheme.
HGQ-0190	Inner part of shrink wrapped section of lead has discolored areas.
HGQ-0192	The pressure on the lower pressure gauge was -3000 psi.
HGQ-0194	The kapton insulation had many shorts during the insulating process. From 37' to 120' was the problem area.
HGQ-0193	Copper stabilizer of double lead ruined while removing from soldering fixture. Superconducter side also slightly disformed.
HGQ-0195	Inner section of ramp up insulation was cut.
HGQ-0196	Due to non functional maesurment table, these measurements were performed using a measuring tape.
HGQ-0197	Due to coil size data discrepancies this coil was re-measured per step 5.0 in traveler.
HGQ-0198	Due to non functional measurement table, these measurements were performed using a measuring tape and caliper.

HGQ-0199	During the lead end end compression test, a drop in resistance was noticed at 3300 pump pressure and progressively got worse to the allotted pressure allowed. There seems to be a turn to turn short on this coil. The "Q" reading also affirms this problem.
HGQ-0200	On the b-side of the coil 6' 7" to 6' 10", the outer layer of the cable insulation is cut and peeling up. Also the power lead has pulled away from the coil on the lead end.
HGQ-0201	Measuring table not functional. Measure by measuring tape.
HGQ-0202	Measuring table not functional. Have to measure using measuring tape
HGQ-0204	As a result of numerous end compressions to locate and identify suspected turn to turn short per DR #HGQ-0199 the coil has the following: A. Numerous pin holes in cable insulation as a result of turn to turn resistance testing, (underside of coil lead e
HGQ-0215	Step 7.0 dictates the installation of the voltage taps. Voltage taps are not to be installed on this coil.
HGQ-0218	Step 7.0 dictates the installation of voltage taps. Voltage taps are not to be installed on this coil.
HGQ-0219	End shimming on end saddles on both lead and return end to be modified. The last approx. 1/2" towards the ends of the coils to be cut off.
HGQ-0220	End shimming on end saddles on both lead and return end to be modified. The last approx. 1/2" towards the ends of the coil to be removed.
HGQ-0221	End shimming on end saddles on both lead and return end to be modified. The last approx. 1/2" towards the ends of the coil to be cut off.
HGQ-0222	End shimming on end saddles on both lead and return end to be modified. The last approx. 1/2" towards the ends of the coil to be removed.
HGQ-0216	Incorrect parting plane part issued and installed. Parting plane part #MD-344469 was issued and installed. Part #MD-344469 rev. A should have been issued and installed. Installed insulation will be removed and correct insulation installed.
HGQ-0214	Step 7.0 dictates the installation of the voltage taps. Voltage taps are not be installed on this coil.
HGQ-0213	End shimming on end saddles on both lead and return ends of coil to be modified. The last approx. 1/2" of insulation towards the ends of the coil to be removed.
HGQ-0212	End shimming on end saddles on both lead and return ends of coil to be modified. The last approx 1/2" of insulation towards the ends of the coil to be removed.
HGQ-0211	End shimming on end saddles on both lead and return ends of coil to be modified. The last approx. 1/2" towards the ends of the coil to be removed.
HGQ-0210	Step 7.0 dictates the installation of voltage taps. Voltage taps are not to be installed on this coil.
HGQ-0209	Step 7.0 dictates the installation of voltage taps. Voltage taps are not to be installed on this coil.
HGQ-0208	Step in the traveler dictates to install voltage taps. Voltage taps will not be installed on this coil.
HGQ-0207	End shimming on end saddles on both lead and return ends to be modified. The last approx. 1/2" towards the ends of the coils to be cut off.
HGQ-0206	Step 7.0 reflects the installation of voltage taps. Voltage taps are not to be installed on this coil.
HGQ-0217	Step 7.0 dictates the installation of voltage taps. Voltage taps are not to be installed on this coil.

HGQ-0225	The inspection table is not being used for coil lengths.
HGQ-0226	The inspection table is not being used for the coil lengths.
HGQ-0234	The inner coils are much longer than the outer coils in length.
HGQ-0227	Coil installation was done out of sequence.
HGQ-0228	The inner ramp lead is longer than the outer g-11 keys.
HGQ-0229	Step 6.5 dictates the installation of the IORS voltage tap. The installation of the 1/4 coil voltage taps has changed.
HGQ-0230	The Ls and Q measurements for all of the individual inner and outer coils are outside of the specified limits given.
HGQ-0231	Heater Strip 2/3 resistance is well above given limits. After testing a fourth time, resistance came to within limits. Movement of return end of heater strip seems to affect resistance.
HGQ-0232	Collar packs not installed per assembly drawing. Inner and Outer cap gage packs installed at lead end. Cap gage packs installed approximately 2.5" from the back of the lead end keys.
HGQ-0233	During hipot testing, the coil was found to have a coil to ground short at 4.5 kV.
HGQ-0235	Inductance and "Q" readings are out of the limits set for them.
HGQ-0236	During the coil to ground hipot, Coil No. MQXBO-022 shorted to ground at 1.1 kV.
HGQ-0237	During the disassembly of groundwrap on the MQXBO-022 coil, a cut in the strip heater was found.
HGQ-0238	L & Q readings are out of the predetermined limits.
HGQ-0239	Fuji film was not used on the lead end end can installation as per Rodger Bossert.
HGQ-0240	The gap measured was greater than the .010" allowed.
HGQ-0241	IORS tap wires will not fit through the End Ring on the Lead End. IORS = 1/8 coil taps
HGQ-0242	The inner return end key in Quadrant 3 is protruding into the bore of the magnet.
HGQ-0254	During warm bore testing the collared coil was found to have a coil to ground short to the lead end end can. Further investigation of the short found that the Q3 voltage tap wire from the inner/outer splice was the cause.
HGQ-0262	Step dictates to install yoke packs into assembly with a 1.650" gap between the straight section yoke pack and non-lead end yoke stack for routing wires. This assembly does not have any wires that need to be routed through this gap as in previous assembl
HGQ-0263	A sixth pass of weld was added to the cold mass.
HGQ-0265	The lead end skin was cut to the specified dimension given in the traveler. Upon setting up to cut the return end skin it was found that the lead end skin appears to have been cut to an incorrect dimension.

HGQ-0267	Overall length of skin will be .500" short if skin length is cut per traveler.
HGQ-0268	During the hipotting procedure of coil to ground, the magnet shorted out at 4 KV. It was determined that the Q3 ramp splice tap was shorting to the end can.
HGQ-0270	The non-lead end outer saddles are cracked in the center of each saddle and they are bulging out from the face of the magnet.
HGQ-0271	Through holes in bullet pusher plate do not line up with tapped holes in coil saddles.
HGQ-0273	There are no provisions in the bullet pusher plate to allow the heater wire voltage tap wires to pass through.
HGQ-0281	1. Step dictates to assemble bullet assemblies MD-369293 assembly number should be MD-369731. 2. During the assembly of the Bullet Assemblies it was found that the 4-40 x 1/4" slotted flat head machine screws are too short.
HGQ-0284	One of the support block bases has been changed. Need the new base.
HGQ-0285	Part # 369875 has a bored hole for a cap screw that is too shallow.
HGQ-0286	Fastener for the support block top does not fit for base #369875.
HGQ-0287	The support block bolt for quadrant 1 & 2 outer coils interferes with power lead support bracket being installed.
HGQ-0288	Support Blocks are installed and power wires need to be attached to stabilizers and insulated. Insulation scheme needs to be specified on drawings and in traveler.
HGQ-0289	During the installation of the splice support blocks it was noticed that the ends of the splices are cut flush with the ends of the blocks. This may cause problems during future assembly as to the proximity of the ends of the un-insulated splices and the
HGQ-0290	Magnet was found to have a circuit A heater to ground failure at 3Kv.
HGQ-0298	Due to replacing endplate the bullets stick out of endplate.

Table 9.0.1 MQXB01 Discrepancy Reports