MQXB02 Fabrication Report

TD-02-038

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1.0 Introduction

MQXB02 is the second production cold mass to be built in the LHCIR Quadrupole series. It was preceded by one prototype, P1 (described in TD-02-009) and MQXB01 (TD-02-027). MQXB02 design is essentially the same as MQXB01. Like all production cold masses, 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 is 38mm, 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 MQXB02 are listed below in Table 1.0.1. Changes from the previous cold mass are highlighted in red and italicized.

Inner Cable Strand No.	37
Inner Strand Manufacturer	Alsthom
Inner Cable lay direction	Right Lay
Outer Cable Strand No.	46
Outer 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	7/1/01
Cold Mass Completion Date	2/15/02

Table 1.0.1 MQXB02 features.

2.0 Superconducting Cable

2.1 Cable Mechanical Parameters

Tables 2.1.1 and 2.1.2 summarize the cable parameters used in MQXB02. 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. 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.

PARAMETER	UNIT	INNER CABLE	OUTER CABLE
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 MQXB02.

PARAMETER	UNIT	INNER CABLE (MQXB02)	OUTER CABLE (MQXB02)
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 MQXB02.

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 MQXB02. Note that the adhesive on the outer wrap of both inner and outer cable is modified polyimide (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: MQXB02 cable insulation parameters.

3.2 Winding and Curing

Five inner and five outer coils were wound, cured and measured for MQXB02. 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 MQXB02 and their corresponding average size and modulus.

Coil Numbers	SIDE A µm	E(A) GPa	SIDE B µm	E(B) GPa
MQXBi-025	292	9.6	288	9.8
MQXBi-026	282	8.3	279	8.5
MQXBi-027	313	10.0	313	10.1
MQXBi-028	304	9.7	319	9.8
MQXBo-024	197	8.8	201	9.0
MQXBo-025	184	9.4	180	9.2
MQXBo-026	224	10.2	229	10.4
MQXBo-027	217	9.6	224	9.5

Table 3.3.1: MQXB02 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.

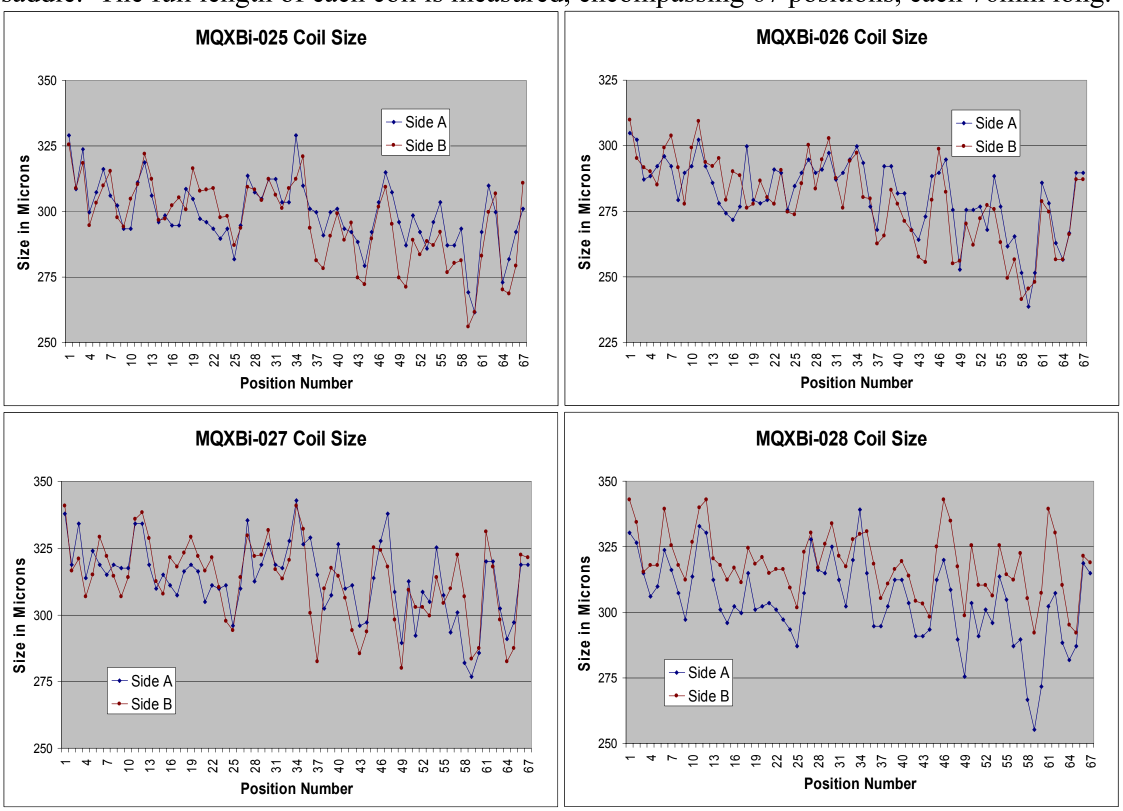


Figure 3.3.1: Variation of size along the length of inner coils.

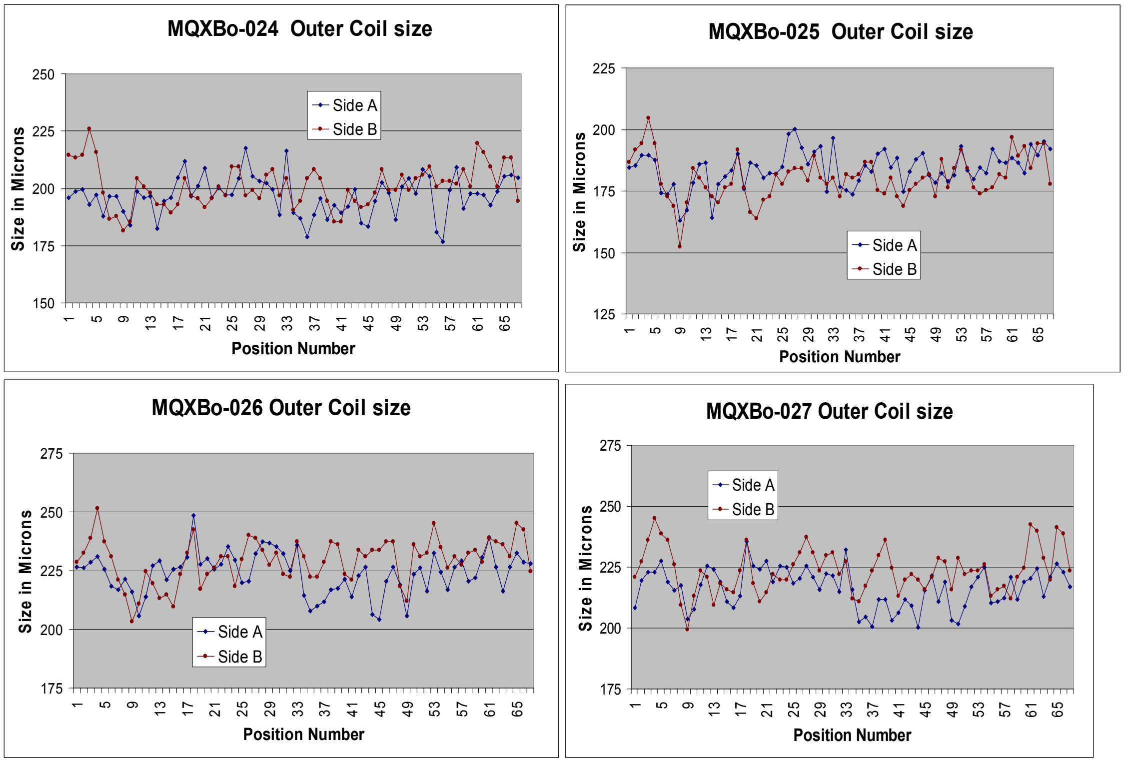


Figure 3.3.2: **Variation of size along the length of outer coils.**

3.4 Coil Shimming

3.4.1 Coil Straight Section

I/O	Quadrant	Coil #	Coil Size µm	Pole Shim µm	PP Shim µm	Target µm	Shimmed Coil Size µm
Inner	1A	i-025	292	0	0	300	292
Inner	1B	i-025	288	0	0	300	288
Inner	2A	i-028	304	0	0	300	304
Inner	2B	i-028	319	0	0	300	319
Inner	3A	i-026	282	0	0	300	282
Inner	3B	i-026	279	0	0	300	279
Inner	4A	i-027	313	0	0	300	313
Inner	4B	i-027	313	0	0	300	313
Outer	1A	o-024	197	0	0	250	197
Outer	1B	o-024	201	0	0	250	201
Outer	2A	o-026	224	0	0	250	224
Outer	2B	o-026	229	0	0	250	229
Outer	3A	o-025	184	0	0	250	184
Outer	3B	o-025	180	0	0	250	180
Outer	4A	o-027	217	0	0	250	217
Outer	4B	o-027	224	0	0	250	224

Table 3.4.1: Kapton shimming used in the 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 MQXB02 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 sizes in MQXB02 varied from 279 to 319 µm with an average of 299 µm; whereas the outer coil size varied between 180 and 229 µm with an average of 207 µm. Table 3.4.1 lists the coil and shim sizes used in MQXB02 (in the case of MQXB02, no shims were used):

3.4.2 Coil Ends

Resistance readings were taken while compressing the ends of the MQXB02 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 MQXB02 coil were shimmed azimuthally with sheets of 125 um thick kapton, according to a formula that was established on the last short models (HGQ07-9), as are all long production coils. Shimming is shown in Figure 3.4.1 and is recorded in FNAL drawings 5520-MD-369695 and 5520-MD-369696. Dimensions in Figure 3.4.1 are in mm.

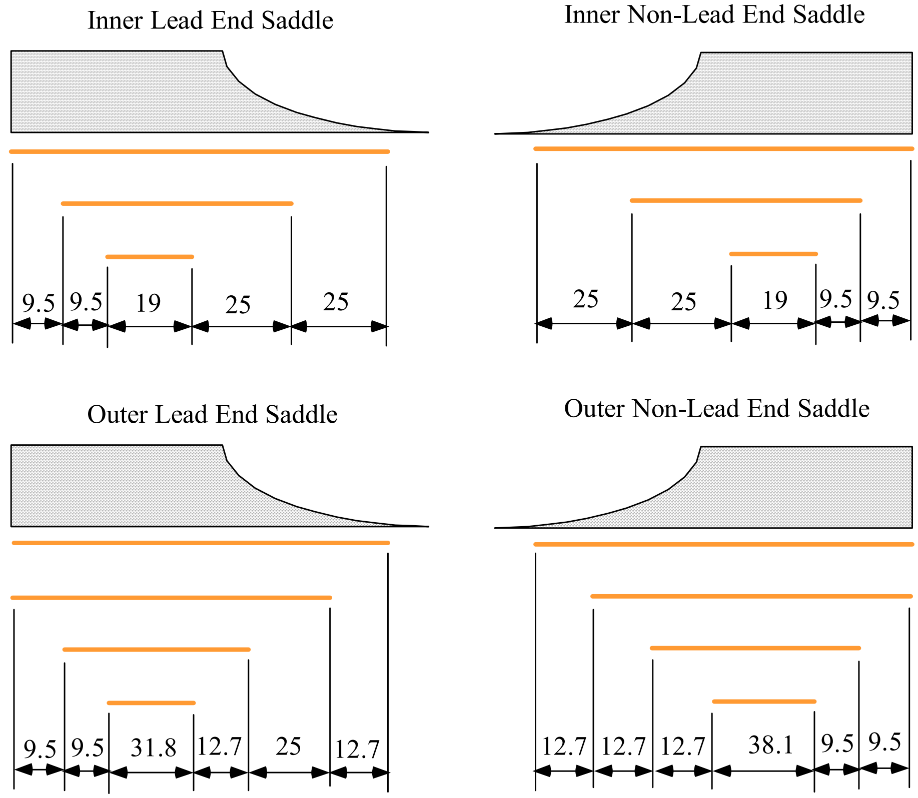


Figure 3.4.1: End-Shimming on MQXB02.

3.5 Voltage Taps

Quench characterization voltage taps and spot heaters were not used on MQXB02, and are not used on any MQXB production magnets. Since MQXB02 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. As in all production magnets, MQXB02 includes ¼ coil taps, ½ coil taps, and taps on the leads as they exit the magnet.

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., 296i, 209o, for Q1/2) show the "after arrangement and shimming" sizes of the inner and outer "octant pairs", respectively, in microns.

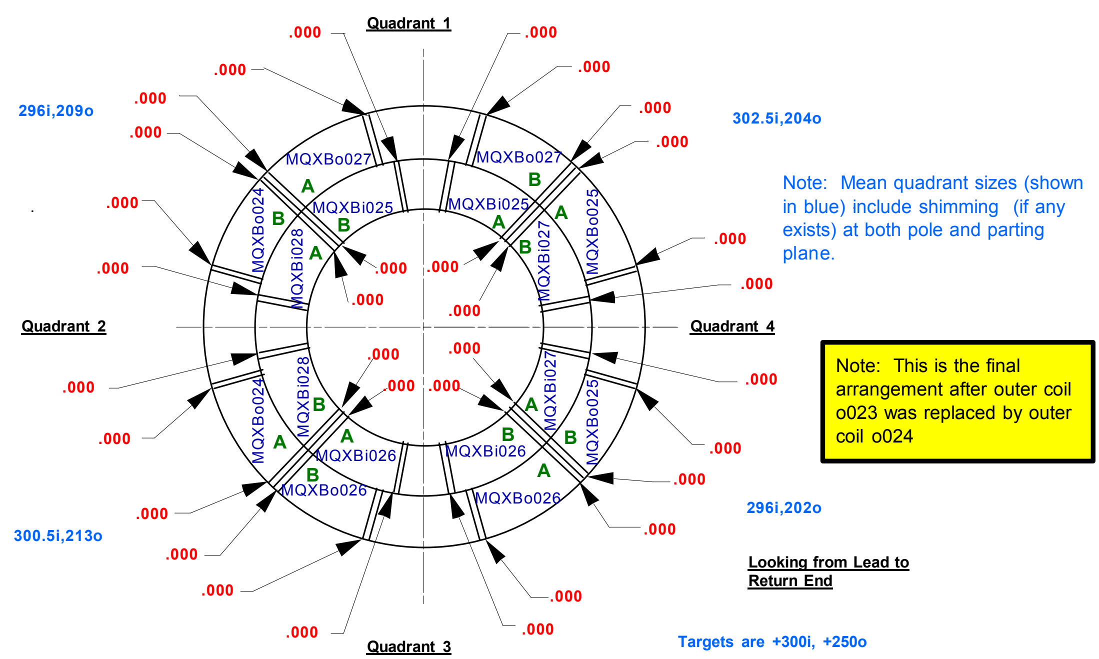


Figure 4.1.1 MQXB02 Coil Arrangement

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 MQXB02 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 pole 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 MQXB02 is shown in Figure 4.3.1. A complete description of the ground wrap system for MQXB02, 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.

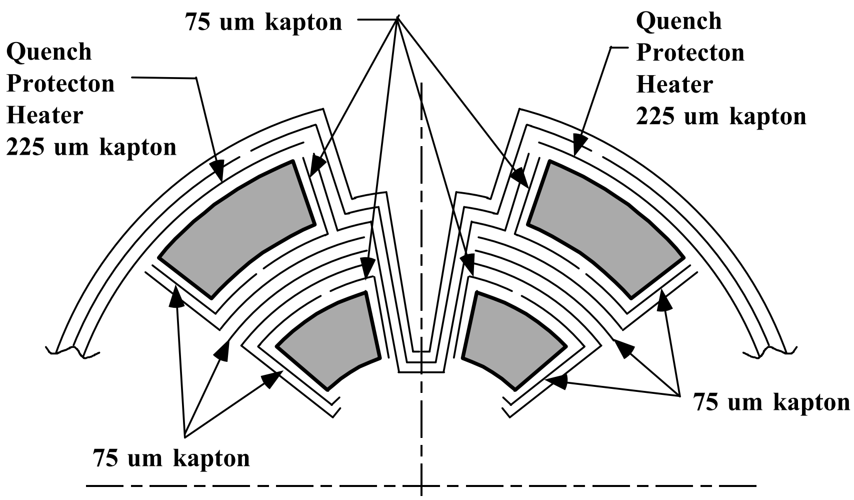


Figure 4.3.1 MQXB02 Body Coil and Ground Insulation System

5.0 Collaring and Keying

5.1 Collaring

To ensure that the splices are aligned properly, the coils are assembled so that the back surface of the lead end keys of all four quadrants in both layers are coplanar. The back surfaces 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. The collared coil assembly 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.

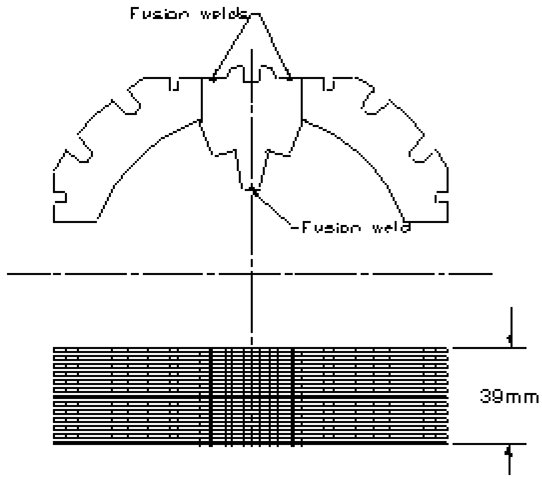


Figure 5.1.1: Collar pack.

As in all production magnets, MQXB02 does not include beam gauge packs or capacitor gauge packs to measure coil preload.

5.2 Keying

MQXB02 was keyed according to procedure #TD-02-010. Collaring keys are 6 inches long. Cylinder pressures were increased slightly from the procedure to fully seat the keys. Steps (including press pressures used on MQXB02) are shown below. Passes are done in 6 inch increments, aligned with the keys, unless otherwise noted.

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 4400 pump psi and key cylinder pressure increased to 2700 pump psi
5) 2nd full key insertion pass with main cylinder pressure increased to 4700 pump psi and key cylinder pressure increased to 3300 pump psi
6) 3rd full key insertion pass with main cylinder pressure increased to 5000 pump psi and key cylinder pressure increased to 3600 pump psi, done in 3 inch increments.
7) 4th full key insertion pass with main cylinder pressure maintained at 5000 pump psi and key cylinder pressure increased to 4000 pump psi, done in 3 inch increments.
8) Final pass straddling keys at 5000 pump psi main cylinder pressure and 4000 pump psi key cylinder pressure.

Several shorts (heater to coil, heater to ground, and coil to ground) were found during and after keying. The shorts and their solutions are described in detail in section 9.0).

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.

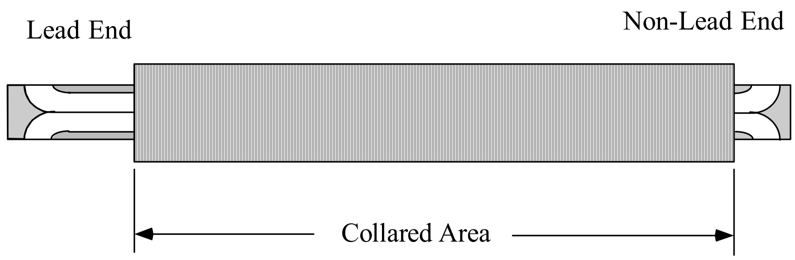


Figure 5.3.1: Collared coil assembly without end clamps installed.

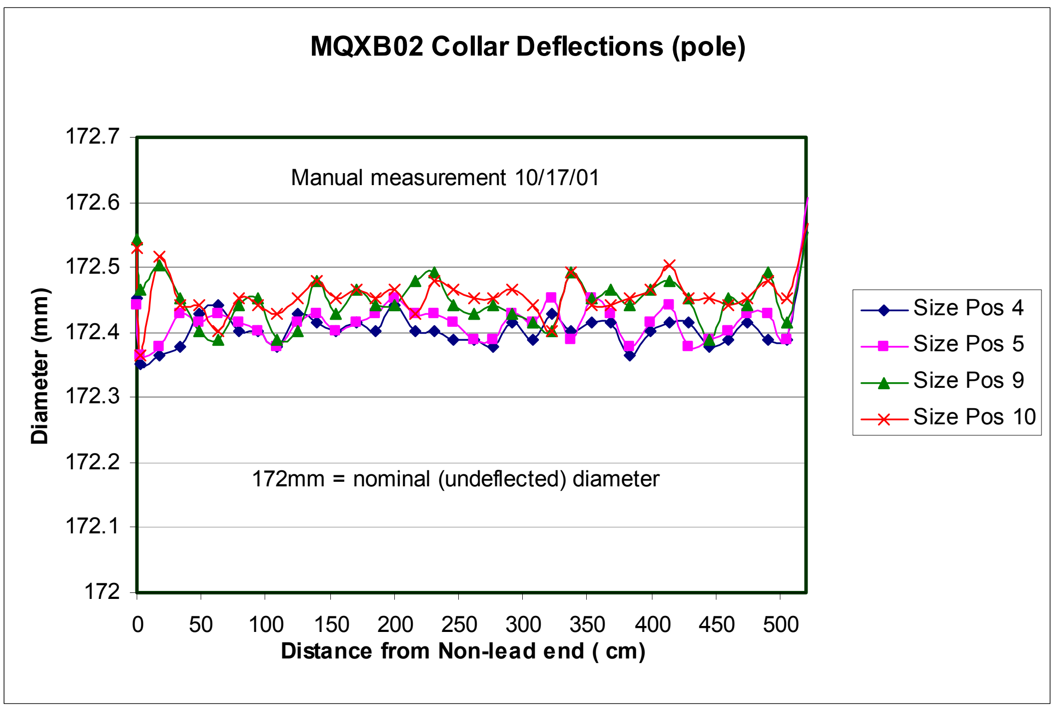


Figure 5.3.2: Collared coil deflections at pole region after keying.

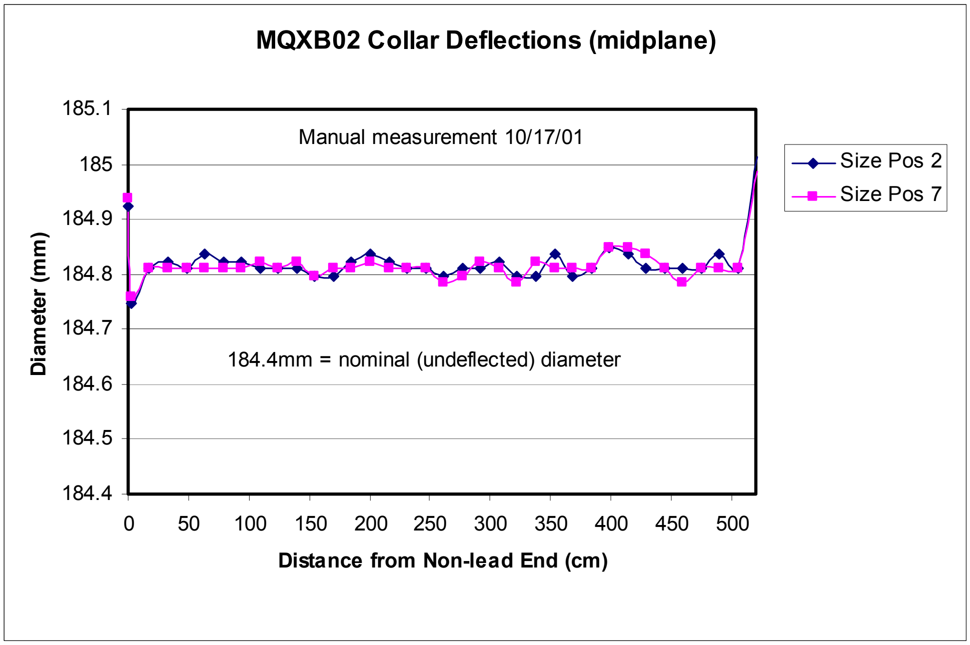


Figure 5.3.3: Collared coil deflections at midplane region after keying.

The measurements show a mean radial deflection of 208 um at the midplane and 212 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 previous long magnets, 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
MQXB02	156	160	208	212

Table 5.3.1: Collared coil deflections of HGQ08-MQXB02.

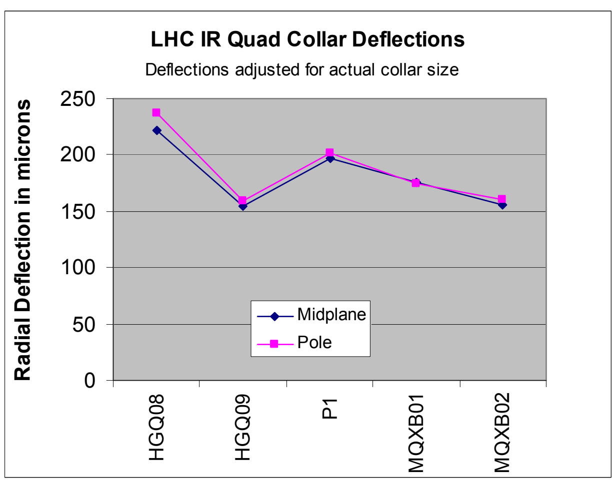


Figure 5.3.4: Collared coil deflections of HGQ08-MQXB02.

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 MQXB02 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 480 kN (108000 lbs.) on the lead end and 187 kN (42000 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, the diameter decreases on the non-lead end, as did the short models, but, unlike the short models, the diameter remains constant or increases slightly as distance from the body increases on the lead end. This is probably attributable to the lead stabilizer, which is soldered to the coil lead over the last 2 cm of 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.

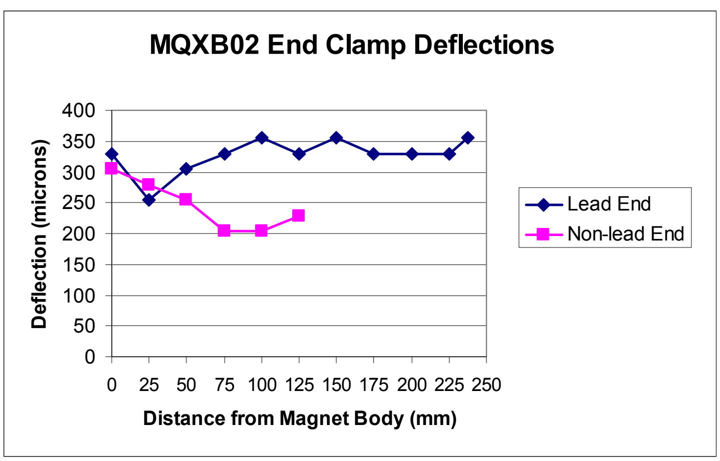


Figure 6.2.1: Aluminum End Can Radial Deflection (Diameter)

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 both lead and non-lead ends 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 5220mm, 11mm 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.

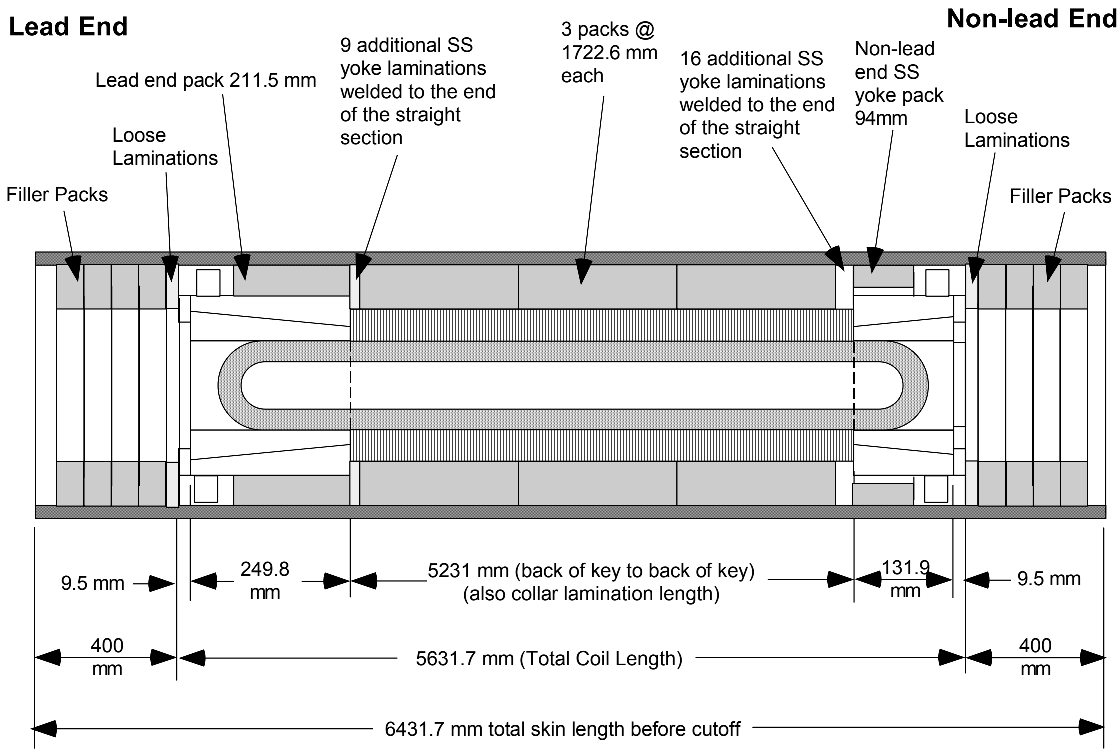


Figure 7.1.1: MQXB02 Yoke Assembly Configuration Before Welding

7.2 Welding:

The skin alignment key was 26.5 mm wide for MQXB02, as are all the long magnets. 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).

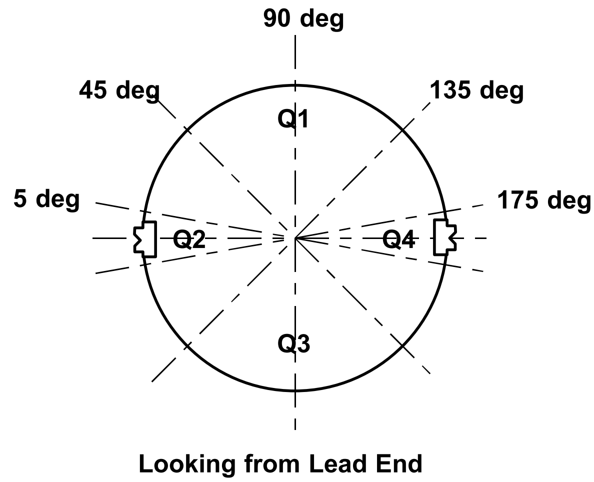


Figure 7.3.1: Yoke Outside Diameter Measurement Positions

Distance from LE (in.)	Distance from LE (meters)	5 deg.	45 deg	90 deg	135 deg	175 deg
0	0.0	418.9	415.0	414.3	415.1	418.6
50	1.3	416.4	416.0	416.0	416.2	416.5
100	2.5	416.7	416.2	416.1	416.3	416.5
150	3.8	416.7	416.2	416.1	416.1	416.4
200	5.1	416.3	416.1	416.0	416.2	416.3
240	6.1	417.9	415.0	415.0	415.3	418.0

Table 7.3.1: MQXB02 yoke outer diameter according to micrometer measurements taken at different angular positions between skin alignment keys

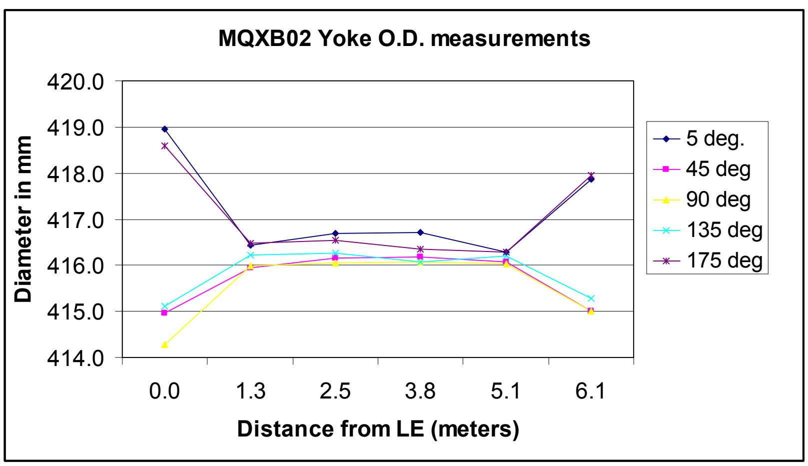


Figure 7.3.2: Yoke Outer Diameter Measurements Plotted

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 0.08 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 .8 milli-radians.

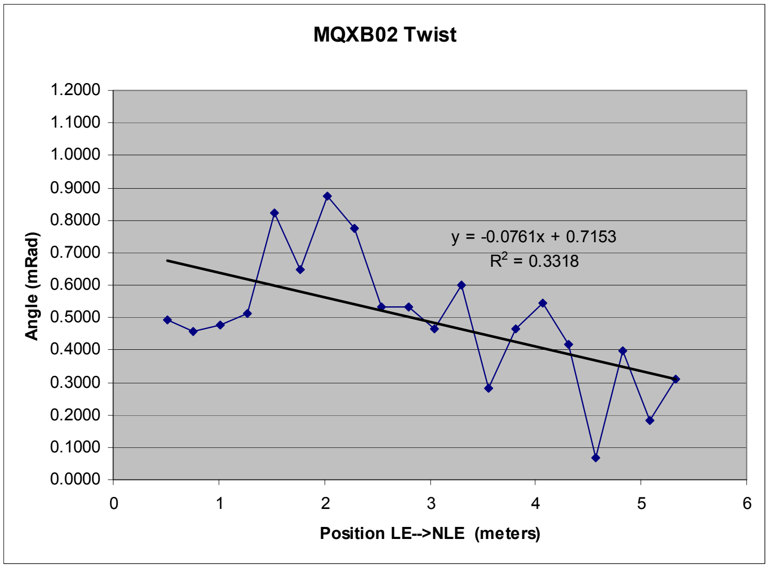


Fig 7.4.1: MQXB02 Cold Mass Assembly Twist Measurements

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 MQXB02 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.

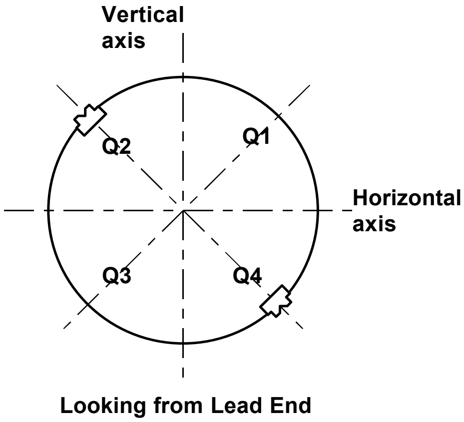


Figure 7.5.1: Straightness Measurement Positions

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

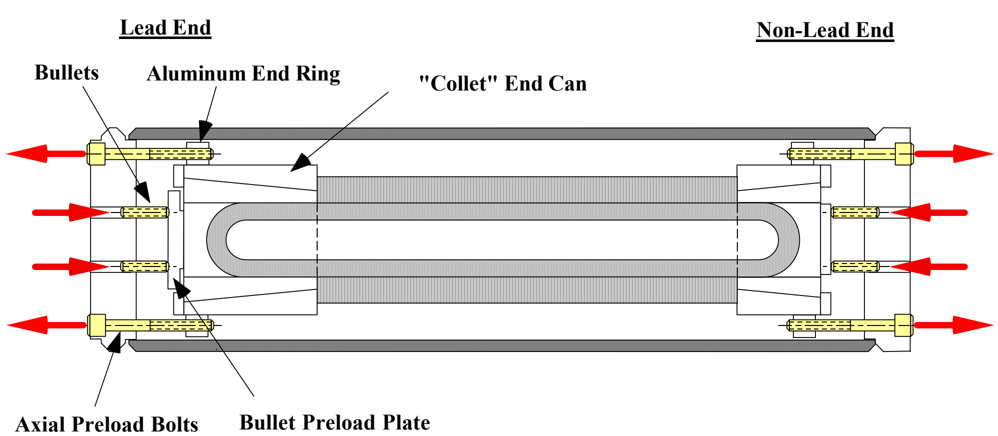


Figure 7.6.1: Axial Support of the Cold Mass Assembly

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 MQXB02, and will not be used on any production magnets. Torque applied to bullets was established from strain gauge readings of short models and the prototype. The complete bullet tightening procedure is explained in FNAL document # 5520-ES-369708, Bullet Torque Specification for LHCIR Quad MQXB Prototypes.

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

MQXB02 was hipotted 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. In Table 8.1.1, coil to ground and strip heater to ground measurements were taken after magnet was completed. The quadrant-to-quadrant measurements were taken slightly earlier, before the quadrant splices were made, because this hipot cannot be made after the quadrants are spliced together.

Hipot	Result
Coil to Ground	150nA at 5000V
Strip heaters to Coil & Ground	72nA at 5000V
Coils Q1 to Coils Q2 across midplane	100nA at 3000V
Coils Q2 to Coils Q3 across midplane	100nA at 3000V
Coils Q3 to Coils Q4 across midplane	100nA at 3000V
Coils Q4 to Coils Q1 across midplane	100nA at 3000V

Table 8.1.1. MQXB02 Hipotting Data

Final electrical data is shown in Table 8.1.2:

	Resistance ohms	**Ls M H**	**Q**
Q1 - inner	.2542	555.508	.73
Q1 - outer	.3176	893.946	1.00
Q2 - inner	.2542	558.732	.74
Q2 - outer	.3173	894.718	1.01
Q3 - inner	.2536	562.406	.75
Q3 - outer	.3177	892.334	1.01
Q4 - inner	.2541	545.233	.94
Q4 - outer	.3175	894.864	1.01
Q1 – Quadrant total	.5716	2.34539	1.99
Q2 – Quadrant total	.5713	2.35695	2.00
Q3 – Quadrant total	.5712	2.34749	1.99
Q4 – Quadrant total	.5714	2.33609	2.33
	Resistance ohms	**Ls MH**	**Q**
Magnet Total	2.292	13.564	4.94

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	19.398
Circuit B	19.476

Table 8.1.3: Heater resistance measurements

8.2 Mechanical Measurements

Design and actual finished longitudinal dimensions of the MQXB02 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 described at the end of Section 5.3.

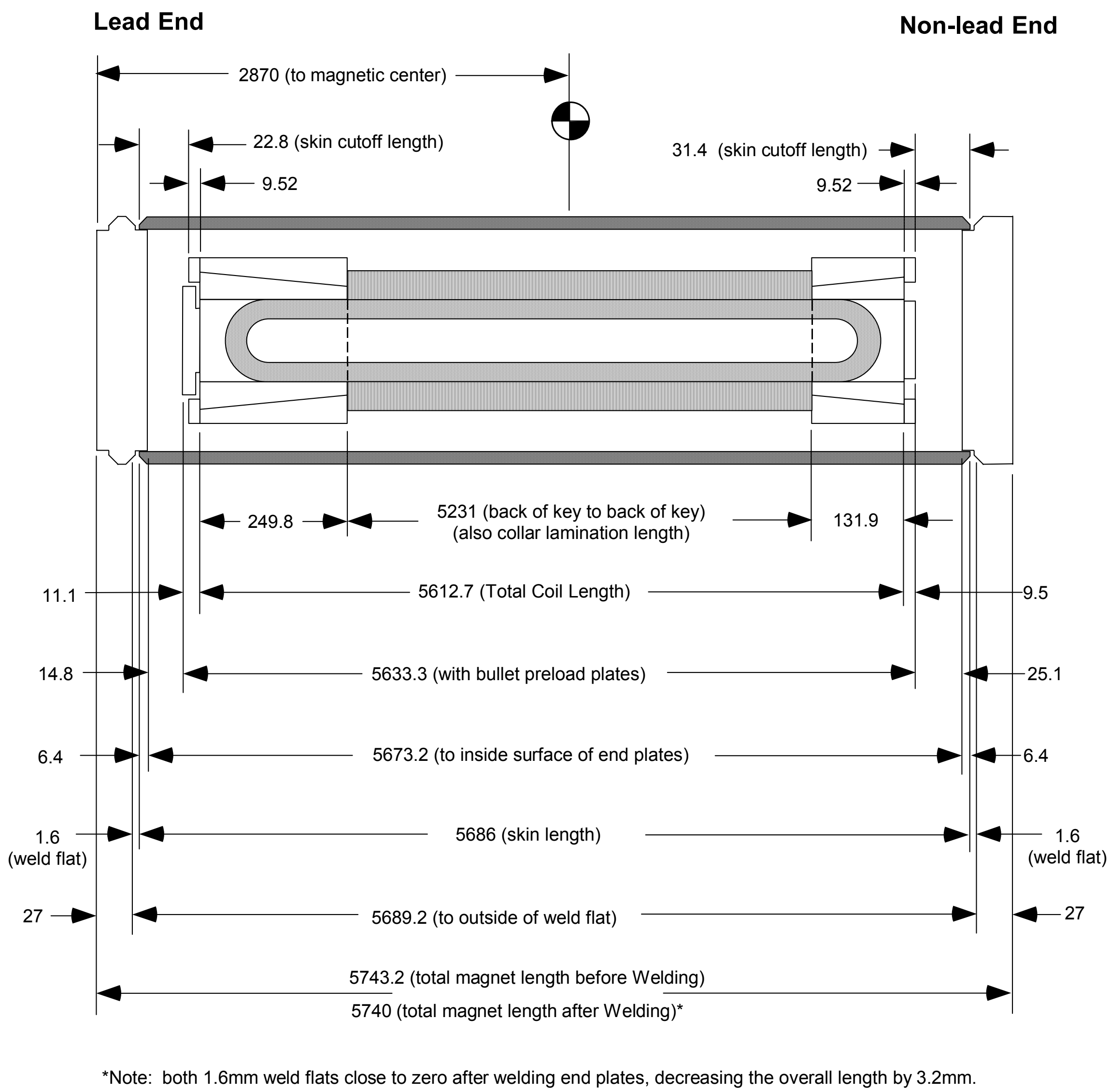


Figure 8.2.1: Design Dimensions of MQXB02

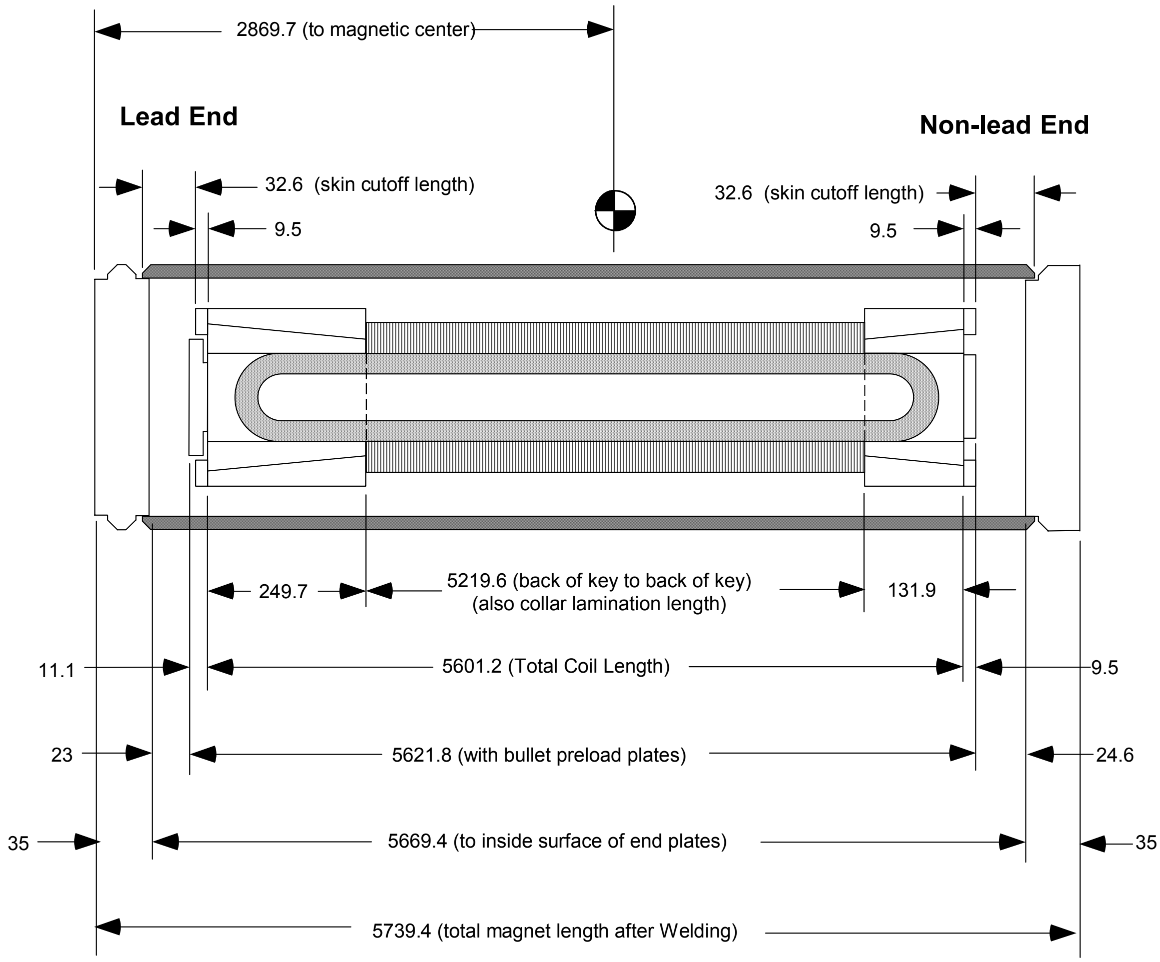


Figure 8.2.2: As-built Measured Dimensions of MQXB02

9.0 Discrepancies and Comments

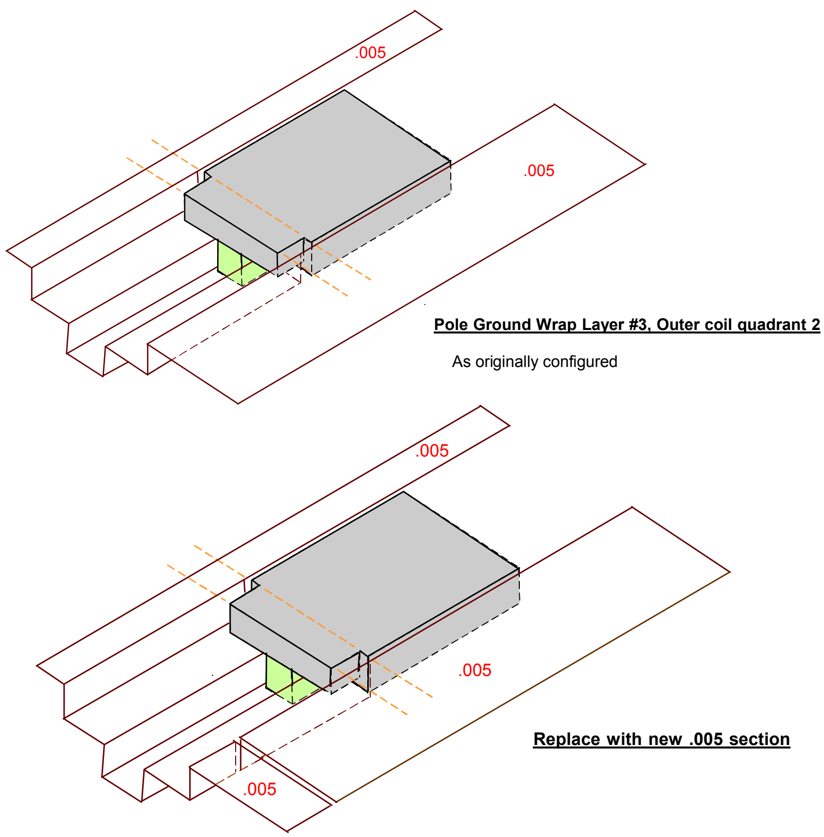
There were several hipot failures during the construction of MQXB02. They are listed below:

1) During the "massaging" part of the keying procedure, a strip heater element shorted to the Q2 outer coil. Determined to be caused by a small (1/32 dia) metal ball, which had been wedged between the collars and the outermost layer of ground wrap. The ball had punched an indentation in the strip heater, causing the insulation on the inside of the strip heater to be punctured, as well as the cable insulation. The ground wrap on the outside of the strip heater (where the ball was) was not punctured, therefore there was no heater or coil short to ground. The magnet was disassembled, the strip heater replaced, the coil (o023) replaced by coil o024, and reassembled. Long term solution was to thoroughly inspect collar packs before assembly to ensure there are no steel fragments. Recorded in DR0259.

2) Heater 2/3 shorts to ground and coils at very low voltage. Found to be a ball of metal (weld slag?) between ground wrap and collars. Area was decollared. Ground wrap was patched per sketch in DR0261. Recollared and rekeyed. Recorded in DR 0261. Long term solution for this as well as 1) is more thorough inspection of collar packs.

3) Heater to ground short after installing end cans. Heater wire was contacting coil where the heater is rolled up at end of saddle. Solution was to remove end can, insulate between the heater and coil, and reinstall end can. Recorded in DR 0283

4) Coil-to-ground short in Q1, failed at 200V. Collar lamination to coil at the end of Q1, similar to that which occurred in MQXB01. Solution for this magnet is the same as done for MQXB01, where the last 12 inches of collar lams were removed, ground wrap patched, key extension used and end clamp installed 3 lams toward body. Long term solution was to round out the corner of the last collar pack to ¼ inch radius, alleviating the pinch point where the gap exists between the "large" and "small" collar laminations. Recorded in DR 0275, and described in Figure 9.0.1 below (dimensions in Figure 9.0.1) are in inches.



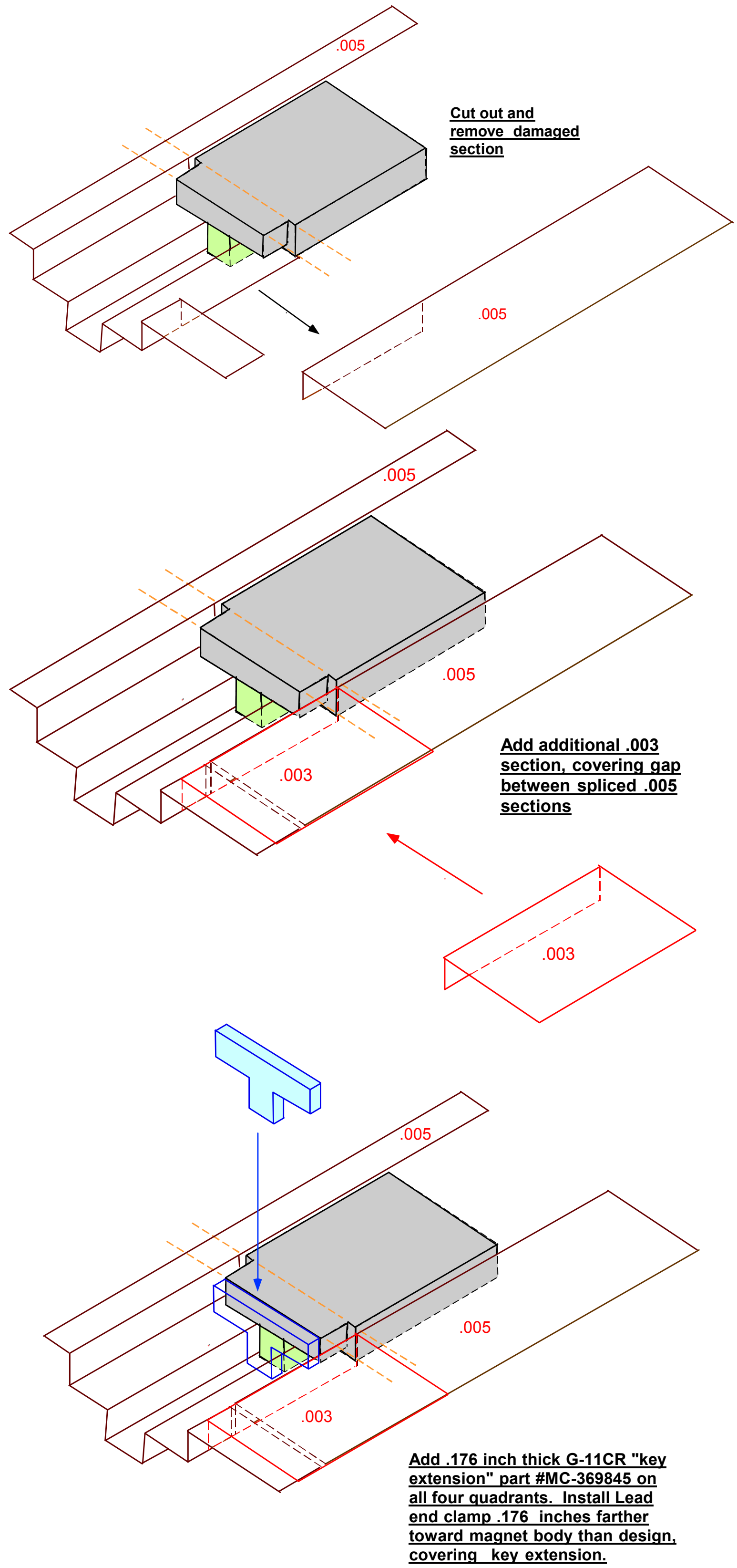


Figure 9.0.1: Ground Wrap Repair

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 MQXB02 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.

DRNo	Component SN	Discrepancy Description
HGQ-0205	MQXBi-025	Had to resize coil due to variance in the resistance that was seen around 150" from the end of the return end saddle
HGQ-0224	MQXBi-025	Step 7.0 in traveler dictates the installation of voltage taps. Voltage taps are not to be installed on this coil.
HGQ-0244	MQXBo-027	Lead pulled away from the coil during the electrical.
HGQ-0246	MQXBi-026	Modifications to previously installed End Shimming not reflected in the traveler or assembly drawings.
HGQ-0247	MQXBi-025	Modifications to previously installed End Shimming not reflected in the traveler or assembly drawings.
HGQ-0248	MQXBi-027	Modifications to previously installed End Shimming not reflected in the traveler or assembly drawings.
HGQ-0249	MQXBi-028	Modifications to previously installed End Shimming not reflected in the traveler or assembly drawings.
HGQ-0250	MQXBC-002	The Inductance and Q readings for the outer coils are out of range. The Amp selector knob setting is wrong. It should be 1A.
HGQ-0251	MQXBC-002	The bare ends of the inner/outer splice has been insulated with .003" adhesive backed kapton to insulate the splice from the la
HGQ-0252	MQXBC-002	Incorrect part number called out in steps 8.3, 9.3 and 10.3 for Pole Ground Wrap Layer #2. Part number should be (MC-369624).
HGQ-0253	MQXBC-002	While inserting the Outer Lead End Keys, there was a gap found to be between the G-11 Outer Lead End Spacer and the Ramp Splice
HGQ-0255	MQXBC-002	All electrical results are out of the limits set for them.
HGQ-0256	MQXBC-002	During collaring massaging the assembly developed a Q2 coil to heater to tooling short. Short is to tooling only and not body
HGQ-0257	MQXBo-024	The return end end saddle is no longer adhered to the coil.
HGQ-0258	MQXBC-002	During collaring it was noticed that the gap between outer layers of ground wrap between quadrants #2 & #3 is no longer apparen
HGQ-0259	MQXBC-002-1	Assembly developed a quadrant 2 coil to collaring tooling short upon completion of the massaging of collars for keying. Short
HGQ-0260	MQXBC-002	Deviated from collar keying procedure in traveler per following: 1. Partial insert keys from LE to RE, 3000 pump psi main cyl
HGQ-0261	MQXBC-002	Heater #2/3 (Heater strip on Quadrant #3) has a dead short to ground and also shorts to coil at a low voltage. Coil to ground a
HGQ-0269	MQXBC-002-2	Coil to Coil short in Q3 - Q4 at Return End.

HGQ-0274	MQXBC-002	During the electrical it was found that the magnet has a Q2/3 heater to Q3 outer coil short. The short has been located and is
HGQ-0275	MQXBC-002	1. Coil to Ground short noted in Quadrant #1. 2. Coil to End Can short noted in Quadrant #3.
HGQ-0282	MQXBC-002-2	Leakage of heater to ground is above acceptable leakage requirements.
HGQ-0283	MQXBC-002-2	Heaters have shorted to coil leads at 4 KV.
HGQ-0292	MQXBC-002	Inner Q1 lead is protruding into the bore of the magnet.
HGQ-0294	MQXBC-002	The measured gaps between the lead end filler cones and collar packs are out of tolerance per travelers.
HGQ-0302	MQXB02	Grooves are not in the collets to putty heater wires into them.
HGQ-0307	MQXB02	One hole for the MB-369875 was not counter bored deep enough for a cap screw.
HGQ-0308	MQXB02	The three support block bases are not cut out enough so the soldered leads fit into the slot provided.
HGQ-0311	MQXB02	Part No. MC-369843 needs to be tapered for the power leads that get tied to them.
HGQ-0313	MQXB02	During the standard 30 second wait at 5000 volts, the hipotter tripped out.
HGQ-0315	MQXB02	Support block 369215 is no longer used.
HGQ-0316	MQXB02	Welds on the skins had to be filed down to allow Part No. MC-390112B to fit properly. A step is needed in the traveler to all
HGQ-0338	MQXBC-002-1	The Inner Coil Leads dropped into the Bore.

Table 9.0.1 MQXB02 Discrepancy Reports