TD-99-042

HGQ-07 Fabrication Report

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Introduction

Model magnet number 7 has only minor differences from HGQ06 in that the inner cable is 37 strand. Cable stability and sharp inner edge were the primary reasons for the change. In an attempt to better understand axial mechanics, end loading is zero for the first two thermal cycles. The cold mass is anchored and suspended from the lead end. All the changes from magnet 6 to 7 are listed below in Table 1.1 and are highlighted in red and italicized.

Inner Cable Strand No.	***37***
Inner Cable lay direction	Left Lay
Outer Cable Strand No.	46
Outer Cable lay direction	Left Lay
Cable Pre-baking	None
Strand Coating	None
Cable Cleaning	Axarel 6100
Inner Cable Insulation	***25uM x 9.5mm w/ 58% overlap surrounded by 50uM x 9.5mm w/2mm gaps w/QI***
Outer Cable Insulation	25uM x 9.5mm w/ 50% overlap surrounded by 25uM x 9.5mm w/41% overlap w/QI
Coil Curing temperature	190C
Inner Coil target size	***+.008 in., +200uM***
Inner Coil MOE	***8.5GPa***
Outer Coil target size	***+.008 in., +200uM***
Outer Coil MOE	***8.5GPa***
Target Prestress	***70-75MPa***
Coil end azimuthal Shim System	Shim ends to be same as body, tapering off toward end of saddle.
End Part Material	G-11
End Part Configuration	Iteration #2, 5 block design.
Splice Configuration	Internal
Voltage Tap Plan	MD-369212/***MD-369259***
Inter layer strip heaters	None
Outer layer strip heaters	***LBL version #2, double element***
Key extension	None
Inner coil Bearing Strips	Brass, cut in 3 inch segments, same as collar packs.

Outer coil Bearing Strips	Phosphor bronze, cut in 3 inch segments, same as collar packs.
Collar configuration	3 inch long "solid" welded packs, with 49 lamination period and dimples for separation.
Collar key configuration	3 inch long, positioned same as packs.
Strain Gauges	4 beam gauges on outer coil, 4 capacitor gauges on inner coil, 4 capacitor gauges on outer coil.
Spot Heaters	Pole turn on 2 outer coils, at lead end on parting plane turn on 1 outer coil.
End Radial Support	Collet end clamps on both ends. Aluminum exterior cans with G-11 quadrant pieces.
Collar/Yoke Interface	Radial clearance between collar and yoke.
Quadrant Lead Configuration	Double lead with copper only cable for stabilizer
End longitudinal loading	***No load applied on first thermal cycle. 2000 lbs. per bullet applied on 3rd thermal cycle, with end cans bolted to end plates longitudinally.***
Yoke Key Width	24mm
Strain Gauges on Skin	Yes
End Plate Thickness	50mm
Tuning Shims	None
Other	Return end keys mold released and replaced. Thermometers on collar/yoke keys. Axial preload bolts are instrumented.
Coil Fabrication Start Date	04/15/99
Collared Coil Start Date	06/15/99
Yoke Assy Start Date	08/09/99
Completion Date	08/30/99

Table 1.1 HGQ07 features.

2.0 Superconducting Cables

2.1 Mechanical Parameters

Table 2.0.1 summarizes the cable parameters used in HGQ-07. Note that the inner cable used in HGQ-07 has 37 strands with left lay pitch direction unlike the previous model magnets. HGQ-01 through HGQ-05 were fabricated with 38 strand, right lay inner cable and HGQ-06 with 38 strand, left lay inner cable. There were no changes in the outer cable parameters.

PARAMETER	**UNIT**	**INNER CABLE FOR HGQ-07**	**OUTER CABLE FOR HGQ-07**
Radial width, bare	mm	15.3813	15.396
Minor edge, bare	mm	1.320	1.051
Major edge, bare	mm	1.610	1.241
Midthickness, bare	mm	1.4776	1.146
Keystone angle	deg	1.162	0.661
Pitch Length	mm	114	102
Number of strands		***37***	46
Lay direction		Left	Left

Table 2.0.1: *Cable mechanical parameters as provided by LBNL.*

The cables were cleaned before insulation with Axarel 6100 in the SSC cleaning module.

2.2 Electrical Parameters

PARAMETER	**UNIT**	**INNER CABLE**	**OUTER CABLE**
R(295 K)	μohms/cm	16.82	18.50
R(10 K)	μohms/cm	0.34	0.47
RRR		49.0	39.36
C/Sc		1.23	1.76

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	19.140	2237	12.97	2,341.70
7	14.340	1676	9.63	1,738.71
8	9.539	1115	6.29	1,135.72

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 HGQ-07. Note that they are the same as in HGQ-06.

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 48% overlap
Outer wrap:		
-material	Kapton tape 50 μm ×9.5 mm	Kapton tape 25 μm × 9.5 mm
-adhesive	Liquid polyimide (QI)	Liquid polyimide (QI)
-wrap structure	Spiral wrap with 2 mm gaps	Spiral wrap with 41% overlap

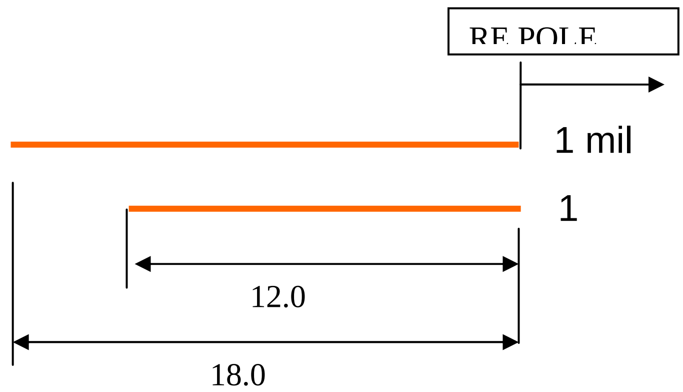
Table 3.1.1: *HGQ-07 cable insulation parameters.*

The wedges were insulated identical to their respective coils.

3.2 Winding and Curing

Five inner and five outer coils were wound, cured and measured for HGQ-07. All coils had wedge breaks staggered such that the breaks would not be coincident at any longitudinal location in the same coil. From the lead end, the wedge lengths were 25”, 22.6” and 19” on one side and 19”, 22.6” and 25” on the other side. The gaps before curing were 0.085”. The variation of the size along the length of the outer coil was closely monitored in this magnet. Appendix - I shows this variation in size for coils used in HGQ-02 through HGQ-06. A peak to peak variation of about 80 - 100 μm was observed consistently in all the outer coils made thus far in HGQ model magnet program. So we decided to add Teflon coated Kapton shim at the parting plane before curing the coil to adjust the size. After couple of iterations we managed to get the variation in coil size down to 40 μm. The parting plane shim used in the last three outer coils (HGQo-047 through HGQo-049) fabricated for this magnet is shown below:

ON SIDE A:



ON SIDE B:

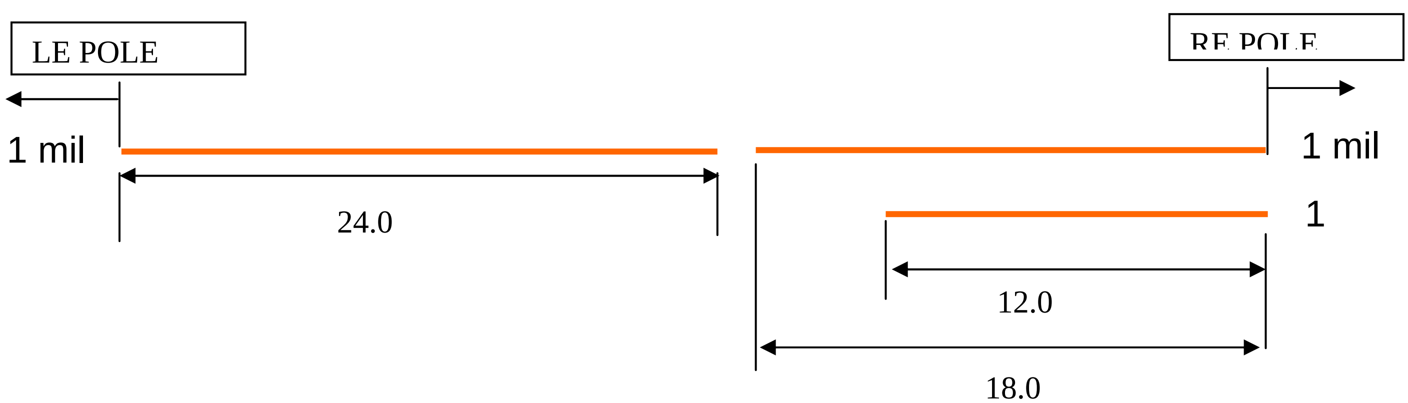


Fig. 3.2.1: *The parting plane shim used in HGQ-07 outer coils before curing to minimize the variation of the size along the length of the coil.*

3.3 Coil Measurements

3.3.1 Coil Straight Section

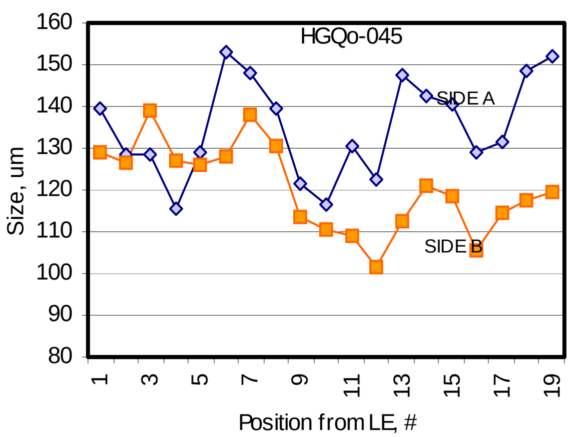
The coil azimuthal size and modulus measurements were taken over a range of pressures, 55 to 100 MPa. The design pressure for both the coils at room temperature is about 65 MPa. Coils were measured with 3 inch gauge length along the straight section of the magnet, from LE to RE. The ends of the magnet were measured separately using end-compression unit and will be discussed in the next section. Table 3.3.1 lists the coils used in HGQ-07 and their corresponding average size and modulus.

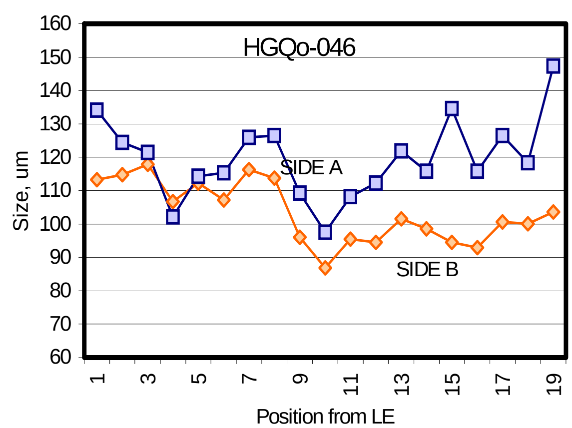
Coil Numbers	SIDE A µm	E(A) GPa	SIDE B µm	E(B) GPa
HGQi-050	137	9.54	152	9.32
HGQi-051	142	8.32	153	7.79
HGQi-052	128	8.20	130	8.13
HGQi-053	131	7.81	134	7.64
HGQo-045	135	8.50	120	8.70
HGQo-046	120	8.10	104	8.40
HGQo-048	128	8.90	116	8.70
HGQo-049	149	9.30	143	9.40

Table 3.3.1: *HGQ-07 coil body size and moduli.*

Note that the target size for both inner and outer coils is +200 µm.

Variation of the size along the length of the coils is shown in Figs 3.3.1 and 3.3.2. Note that Side A is the winding side of the cable and the lead end of the cable is on Side B.





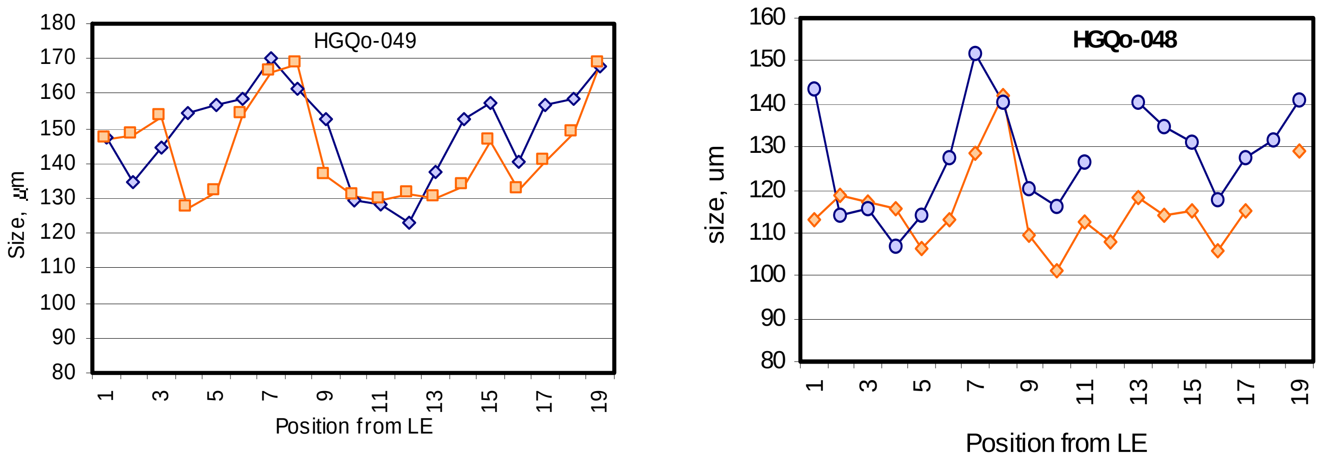


Figure 3.3.1: *Variation of size along the length of outer coils.*

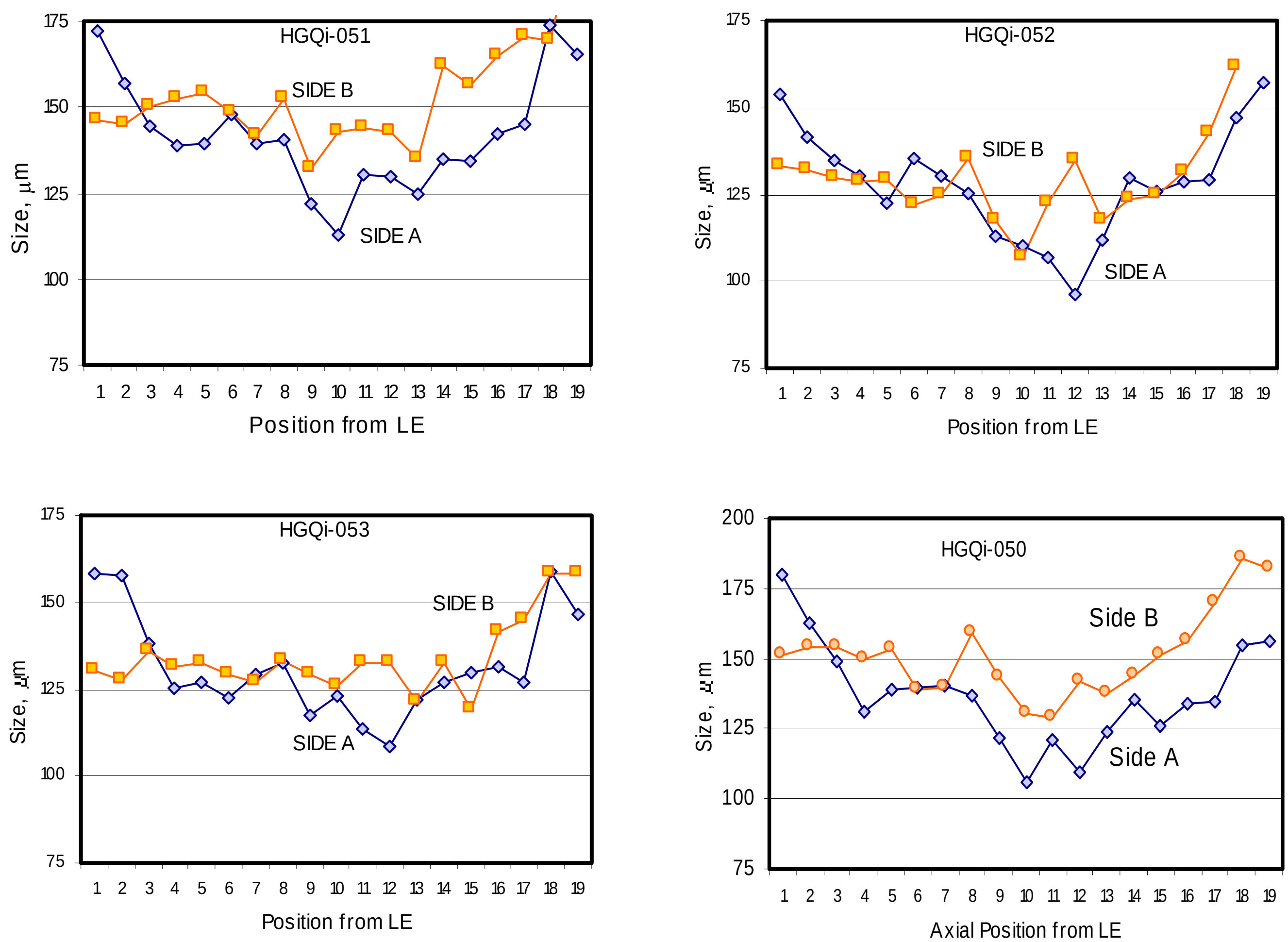


Figure 3.3.2: *Variation of size along the length of inner coils.*

3.3.2 Coil Ends

End-compression experiments performed on HGQ-06 coils were used as a basis for this magnet as the two were fabricated identically.

3.4 Coil Shimming

3.4.1 Coil Straight Section

The target pre-stress for HGQ-07 is about 65 MPa. This corresponds to a nominal coil size of +200 μm for both inner and outer coils. The inner coil size varied from 127 to 152 μm with an average of 138 μm; whereas the outer coil size varied between 104 to 149 μm with an average of 126.5 μm. The following table lists the shim sizes used for both inner and outer coils [*from R. Bossert*]:

I/O	Quadrant	Coil #	Coil Size	Shim Pole	Shim PP	Target	Actual	Mean
Inner	1A	i-051	142	25	50	200	217	
Inner	1B	i-051	152	25	25	200	202	
Inner	2A	i-052	127	25	50	200	202	
Inner	2B	i-052	130	25	50	200	205	
Inner	3A	i-053	132	25	50	200	207	
Inner	3B	i-053	135	25	50	200	210	
Inner	4A	i-050	137	25	50	200	212	
Inner	4B	i-050	152	25	25	200	202	207
Outer	1A	o-046	120	25	50	200	195	
Outer	1B	o-046	104	25	75	200	204	
Outer	2A	o-049	149	25	25	200	199	
Outer	2B	o-049	143	25	25	200	193	
Outer	3A	o-048	127	25	50	200	202	
Outer	3B	o-048	117	25	50	200	192	
Outer	4A	o-045	134	25	50	200	209	
Outer	4B	o-	120	25	50	200	195	199

		045						

Table 3.4.1: *Shimming used in coil straight section.*

3.4.2 Coil Ends

The end-shimming was done identical to HGQ-06. Figs. 3.4.1 through 3.4.2 shows the shim plan.

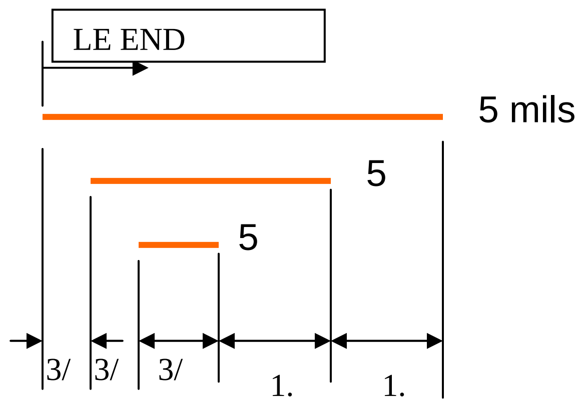


Figure 3.4.1: *End-Shimming for inner coil LE*

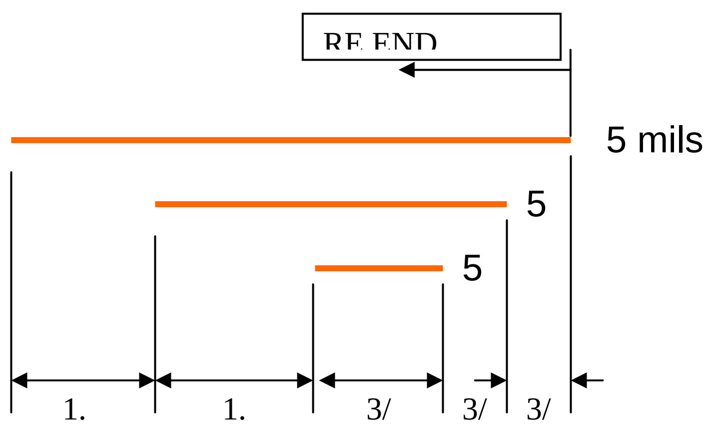


Figure 3.4.2: *End-Shimming for inner coil RE.*

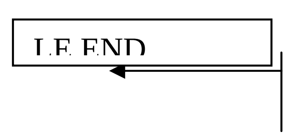
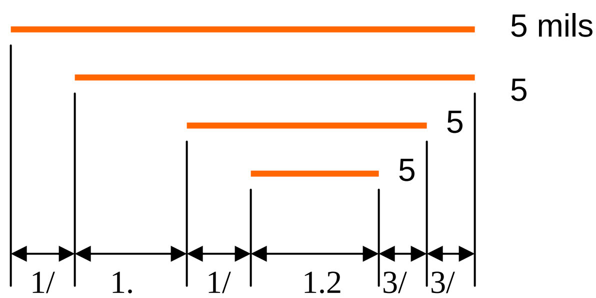


Figure 3.4.3: *End-shimming for outer coil LE*.



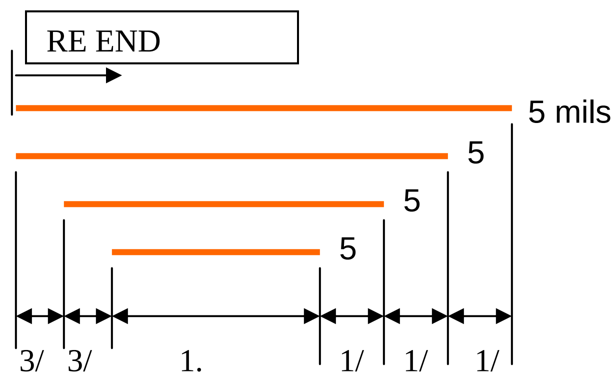


Figure 3.4.4: *End-shimming for outer coil RE*.

3.5 Voltage Taps and Spot Heaters

Voltage taps were mounted according to the drawing number 5520-MD-344972 for inner coils and 5520-MD-344973 for outer coils. End-compression tests with a 5 inch pusher bar were done on all HGQ-07 coils after putting the voltage taps to check for turn-to-turn shorts. None of the coils showed any turn to turn shorts.

During assembly two additional voltage taps were added on either side of the spot heaters mounted between the 16th turn and the G-11 spacer (ramp splice) on outer coils, HGQo-046 and HGQo-048.

Spot heaters were installed between the end-saddle and the last turn during winding on outer coil HGQo-047. Spot heaters were also installed between the 16th turn and the G-11 spacer in outer coils, HGQo-046 and HGQo-048 later during coil assembly.

4.0 Coil Assembly

4.1 Coil Arrangement

Coils in HGQ 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 are frequently 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 x.x for a discussion of coil shimming.

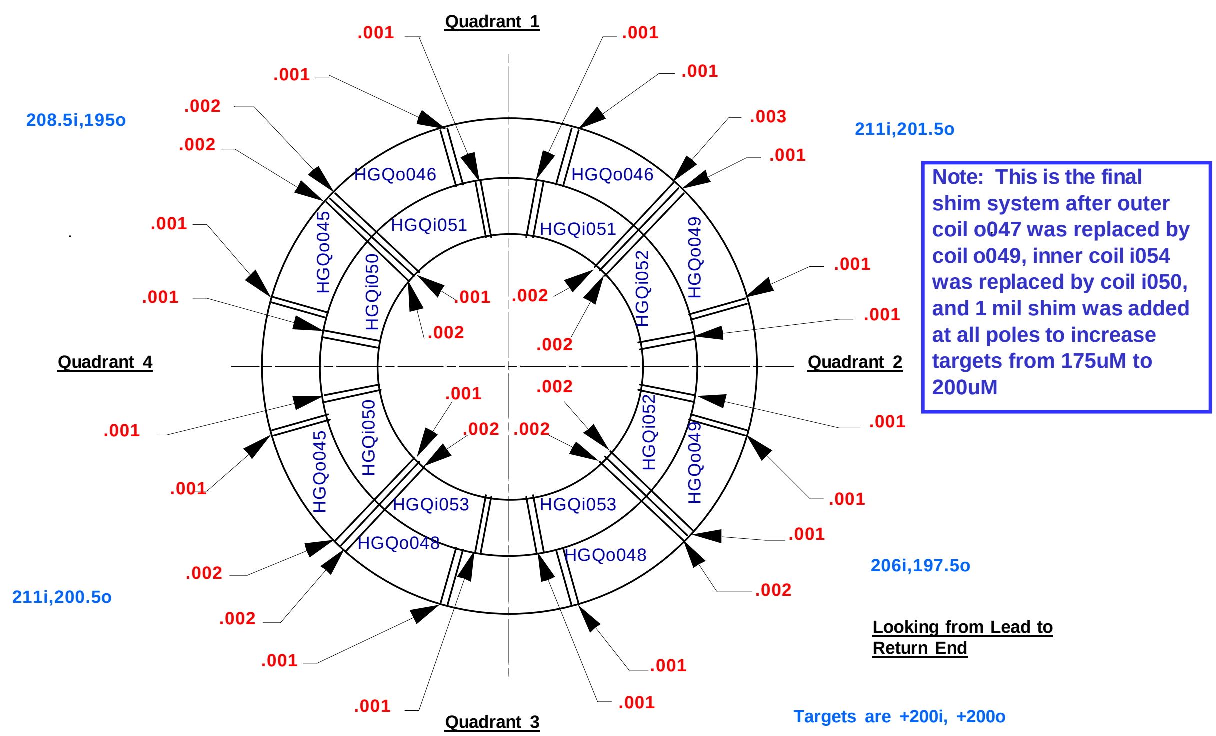
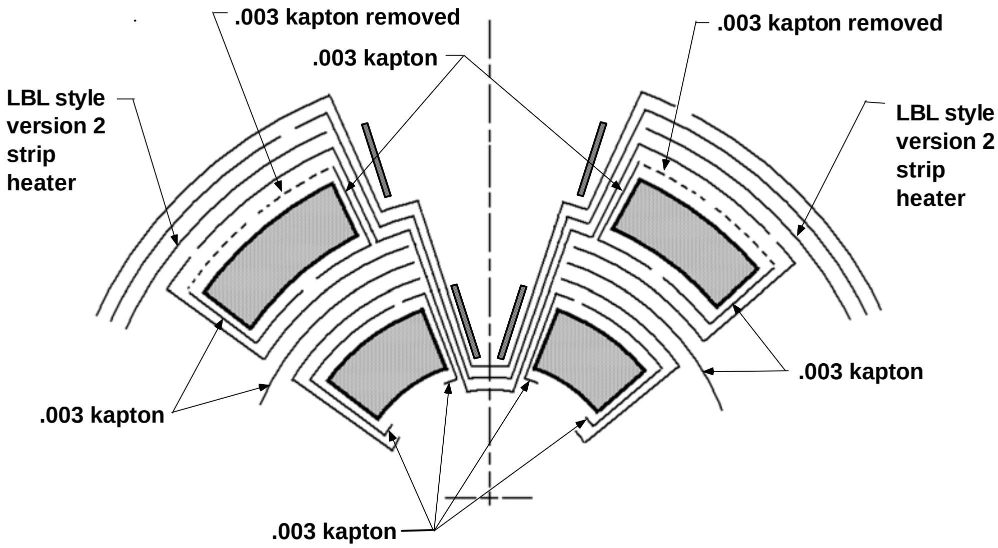


Figure 4.1.1 HGQ07 Coil Arrangement

4.2 Ground Wrap System

The coil insulation and ground wrap systems (body and ends respectively), for HGQ07 are shown in Figures 4.2.1 and 4.2.2. All layers of kapton are .005 inch (125uM) thick unless otherwise specified in the figures. One layer of .003 inch (75uM) kapton was removed between the outer coil and the collars to allow room for the .003 inch thick strip heater. One layer of .003 inch thick kapton was added between the inner and outer coils to take the place of the inter layer strip heater. The original design allowed for a strip heater between the inner and outer coils, but not between the outer coils and collars.



A complete description of the ground wrap system for HGQ07 is shown in drawing 5520-MC-369304.

Figure 4.2.1 HGQ07 Body Coil and Ground Insulation System

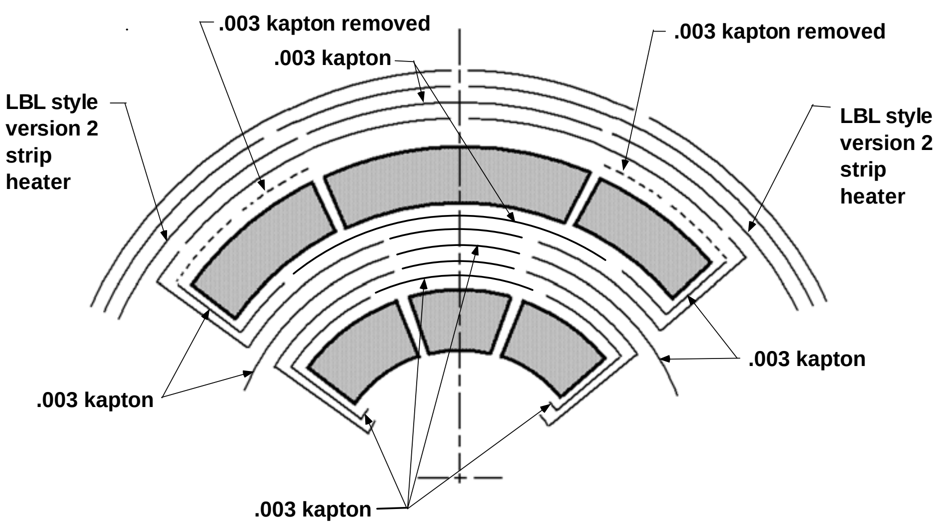


Figure 4.2.2 HGQ07 End Coil and Ground Insulation System

4.3 Strip Heaters

Quench protection (strip) heaters have, at various times, been placed in two different positions in High Gradient Quadrupoles, radially between the inner and outer coils, and between the outer coils and collars. Several different designs have also been used.

HGQ07 has no heaters between the inner and outer layers. LBL style version 2 heaters were used between the outer layers and collars. These heaters are the "double element" style (turnaround on return end), with stainless steel elements, 13/16 inches (20.6mm) wide, copper plated on one side. The copper is etched away over a 31 inch length near the longitudinal center, exposing the stainless. The stainless/copper element is sandwiched between (and bonded to) two pieces of .001 in. (25 micron) thick kapton. They were made for HGQ magnets at LBL. The strip heater is described in detail in drawing #5520-MB-369285.

4.4 Pole Splices

The pole turn of each inner/outer coil pair needs to be spliced together. The internal splice configuration is used for HGQ-07. Splices are 114 mm long, which is approximately equal to the cable transposition pitch. Areas to be spliced are preformed, and filled with solder before the coil is wound. The tinned sections are then spliced after the coils are assembled on the mandrel. A cooling fixture was attached at the coil side so that the coil is not heated excessively. The maximum temperature for the turn next to the heater during the splicing processes was about 140 F.

Two quadrants (Q2, Q4) were spliced using an additional shim. The 30 mil metal shim was introduced into the splice fixture to achieve uniform compression for the cable strands during splicing.

All splices have been insulated with Kapton tape (25 μm×9.5 mm + 50 μm ×9.5 mm), spiral wrapped with 2 mm gap. The 2nd layer of Kapton is placed directly over the first layer, leaving 2mm spaces of uncovered bare cable. Axial and radial cooling channels were made in the G11 spacers which surround the splices as well.

After splicing, all coils were surrounded by ground insulation.

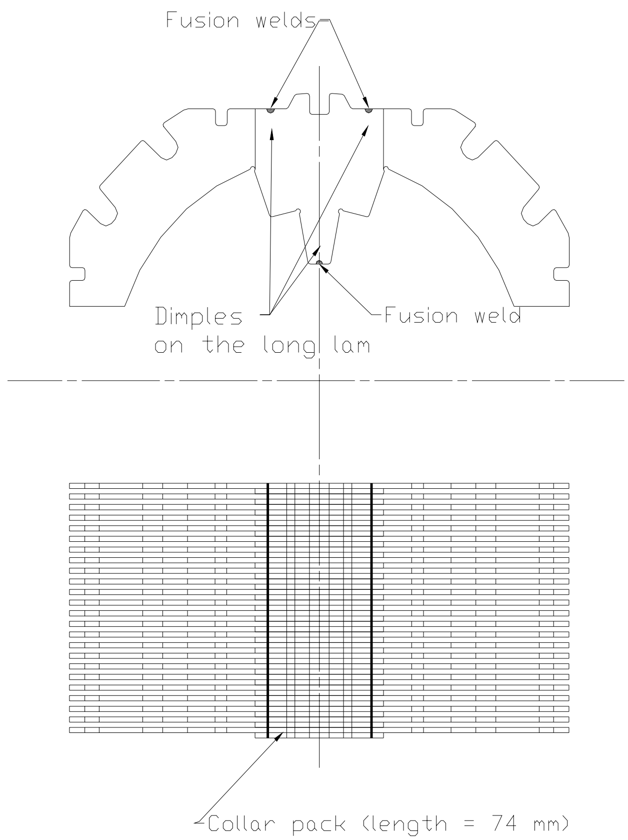
5.0 Collaring and Keying

5.1 Collaring and Keying History

The magnet was collared 3 times and keyed twice. The first collaring was made using very tight assembled collar packs. Due to that, one of outer bearing strip (quadrant 2) on next after RE gauge packs fell down and caused a coil to ground short. It was discovered later by checking resistance between coils and different packs layers insulated from each other. This test was introduced into the latest version of the collaring procedure.

Two beam gauge packs at the return end broke at the fusion welds and it's believed the cause was either different material thickness or spacing between laminations. The magnet was decollared and quadrant 2 was unspliced. The outer coil was replaced with the new coil as well as all layers of coil ground insulation. All quench heaters were tested again by 1500V for leakage purposes to the ground under compression, and weak spots covered by 0.5 mil Kapton tape with adhesive.

At the second iteration we decided to add 1 mil Kapton shim for inner and outer coil at



the pole regions for pre-stress reduction and completely eliminate the return end gauge packs (measures the highest pre-stress where the coils are largest) due to good uniformity of the coils.

Figure 5.1.1 Collar pack.

New collar packs had been made because the original packs were very tight at assembly. To increase the long lamination thickness, three dimples 4 mils high were putted on pole area near weld points. See Figure 5.1.1. Additionally, two combs were used during welding which helped to maintain lamination spacing. Final length of packs after welding become slightly (by 1 lam for 47 lam pack) longer than previous one. The packing factor decrease to 96% and a cooling channel ~ 2-4 mil appeared between each second lamination.

The collar assemblies' interleaf was much easier with the dimples. This however caused concern about the bearing strip detaching from the collar pack and sliding into an adjacent pack causing a short or permanent damage to a coil. To avoid those possibilities, rubber temporarily keys were used to keep coil under compression during massaging time. They were replaced with the metal keys during keying. It worked well.

Inner coil i054 (quadrant 4) developed a turn to turn short during the lead end can installation. A popped strand was suspected and later discovered to be the cause of the short on side A between turns 13 & 12, 4.15 inches from the end of the saddle. The same reassembled procedure took place again. The inner coil was replaced with the new one as well as two layers of ground insulation. Only one quench heater had been checked. All collar packs were reused. The new beam gauges (Sunil's design) had been installed into instrumentation packs at the middle of the magnet.

5.2 Collar Pack Map and Keying Procedure

Several different lengths of collar pack had been used (Fig.4.7). Small bearing strips approximately the same length as packs were used. They were attached to the poles at the pack ends using 0.025 mm (0.001 in) tick adhesive Kapton tape. The first and last packs were insulated at the ends to avoid coil-to-ground shorts, because no key extensions used in the magnet.

The magnet was stacked starting from the Return End using the vertical keying press. The collared assembly was "massaged" at 500,1500 and 3000 pump psi using the main pressure (MP), partially keyed by hand at MP=4500 pump psi. Final keying was done at MP=6500 pump psi using 3000 pump psi of the key pressure (KP). Short 3 in keys were used for keying. The collaring keys cross the welded collar pack boundaries because the keys were a shorter length than pack.

No shorts to ground during keying were observed.

Figure 5.2.1 shows packs location along the magnet body and keying procedure in details.

	HGQ-07 pack's map			I.Novitski														
				8/3/99	key edge	key length	#	installation	in pos.	Massage at	Massage at	Massage at	Partialy keying	Keying at	Keying at	Keying at	Keying at	
					pos in mm	inch				500/0 pump psi.	1500/0 pump psi	3000/0 pump psi.	by hand at	5000/1000	6000/2000	6500/3000	6500/3000	
LE	Q4	Q3	Q2	Q1	from ends					with rubber key	main/key pressure		4500/0 pump psi.	pump psi.	pump psi.	pump psi.	pump psi.	
	49	48	49	48		1.375	1	1	H	20	1	1	1	20	20	20	1 inch shift	
					35												1	
		14		14		3	2	20	V	19	2	2	2	19	19	19		
	13		13		111												2	
	48	49	48	49		3	3	19	V	18	3	3	3	18	18	18		
					187												3	
	49	48	49	48		3	4	18	V	17	4	4	4	17	17	17		
					264												4	
	48	49	48	49		3	5	17	V	16	5	5	5	16	16	16		
					340												5	
	49	48	49	48		3	6	16	V	15	6	6	6	15	15	15		
					417												6	
	48	49	48	49		3	7	15	V	14	7	7	7	14	14	14		
					494												7	
	49	48	49	48		3	8	14	V	13	8	8	8	13	13	13		
Total					570												8	
length is	48	49	48	49		3	9	13	V	12	9	9	9	12	12	12		
59.26 in					647												9	
1506 mm	CG	BG	CG	BG		3	10	12	V	11	10	10	10	1	1	1		
	49	TC 47	49	TC 47	724								"0" reading before at 500		readings at 6500/0, 6500/3000		10	final reading
↗	48	49	48	49		3	11	11	V	10	11	11	11	2	2	2		
cuted					706 / 800												11	
leg	49	48	49	48		3	12	10	V	9	12	12	12	3	3	3		
					630												12	
	48	49	48	49		3	13	9	V	8	13	13	13	4	4	4		
					552												13	
	49	48	49	48		3	14	8	V	7	14	14	14	5	5	5		
					476												14	
	48	49	48	49		3	15	7	V	6	15	15	15	6	6	6		
gap →					400												15	
	49	48	49	48		3	16	6	V	5	16	16	16	7	7	7		
					325												16	
	48	49	48	49		3	17	5	V	4	17	17	17	8	8	8		
					248												17	
	49	48	49	48		3	18	4	V	3	18	18	18	9	9	9		
					171												18	
						1.5	19	3	V	2	19	19	19	10	10	10		
	48	49	48	49	93												19	
						2.25	20	2	V	1	20	20	20	11	11	11		
	49	48	49	48	55												20	
RE	Q4	Q3	Q2	Q1														

CG - cap gauge pack
BG - beam gauge pack
TS - temperature sensor will be installed on the collar allyment key
TC - temperature compensator

Figure 5.2.1 Map of packs and keying procedure.

5.3 Strain Gauge Readings

The final pressures after magnet keying are shown in Table 5.3.1. The strain gauges nearer the lead end are designated "lead end" and the strain gauges nearer the return end are designated " return end", even though the gauges are within the body, and not actually at the lead or return end.

Cap gauges

		HGQ-07.3 final, MPa	HGQ-07.2 final, MPa	HGQ-06 final, MPa	HGQ-05 final, MPa
LE	inner	67	62	64	94
	inner	69	66	57	99
RE	inner			67	109
	inner			76	
LE	outer	70	68	73	
	outer	70	63	67	
RE	outer			50	84
	outer			82	

Beam gauges

		HGQ-07.3 final, MPa	HGQ-07.2 final, MPa	HGQ-06 final, MPa	HGQ-05 final, MPa
LE	outer	62	137	166	35
	outer	55	98	113	47
RE	outer			139	64
	outer			133	54

Table 5.3.1 Final Gauge Readings

5.4 Mechanical Measurements.

The OD measurement data for collared coil block show on Fig. 5.4.2-4.

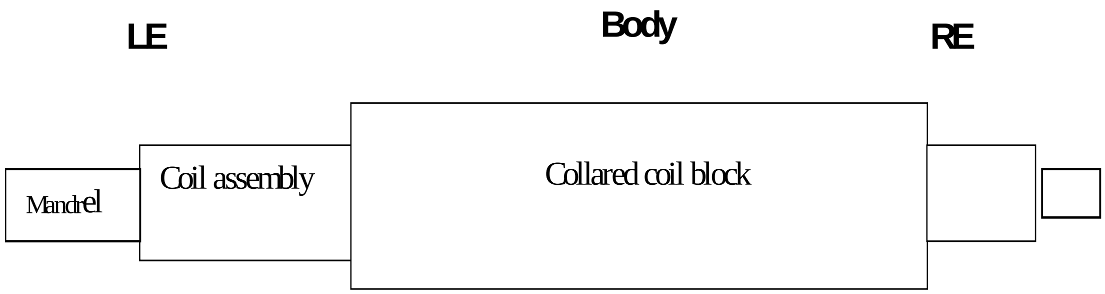


Figure 5.4.1 Collared coils with coil assembly on the mandrel.

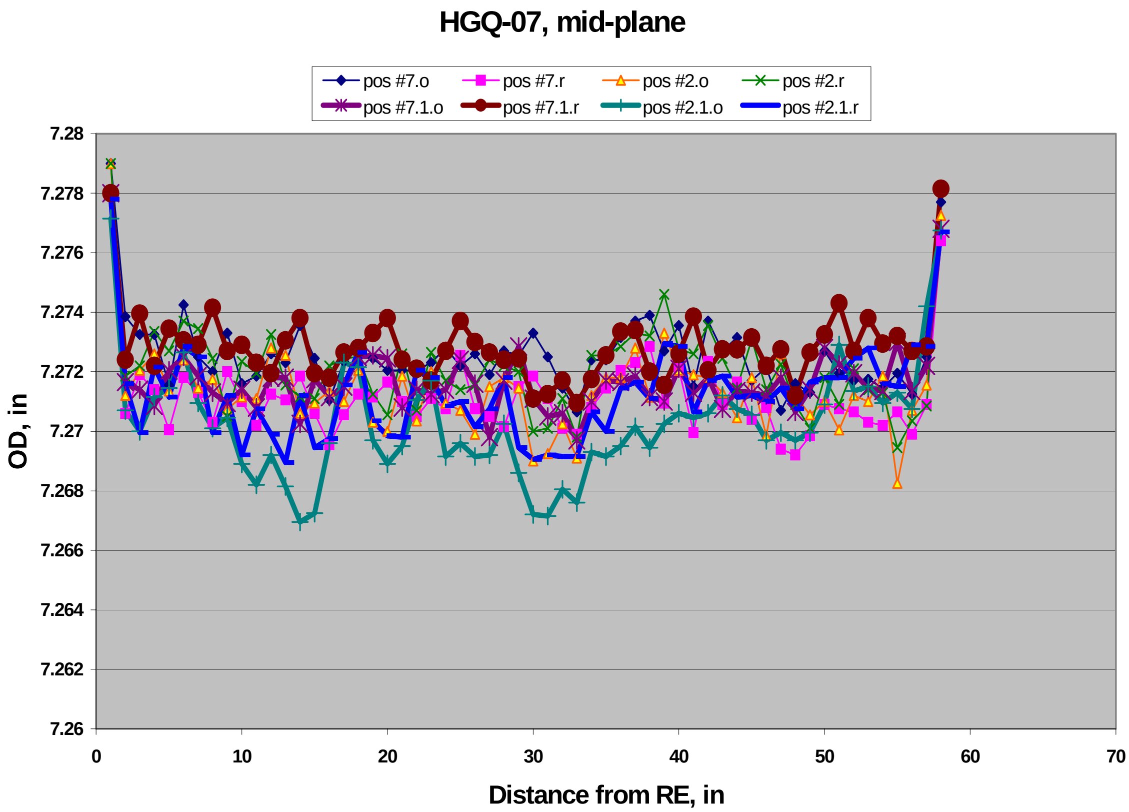


Figure 5.4.2 Collared coil deflections at midplane region.

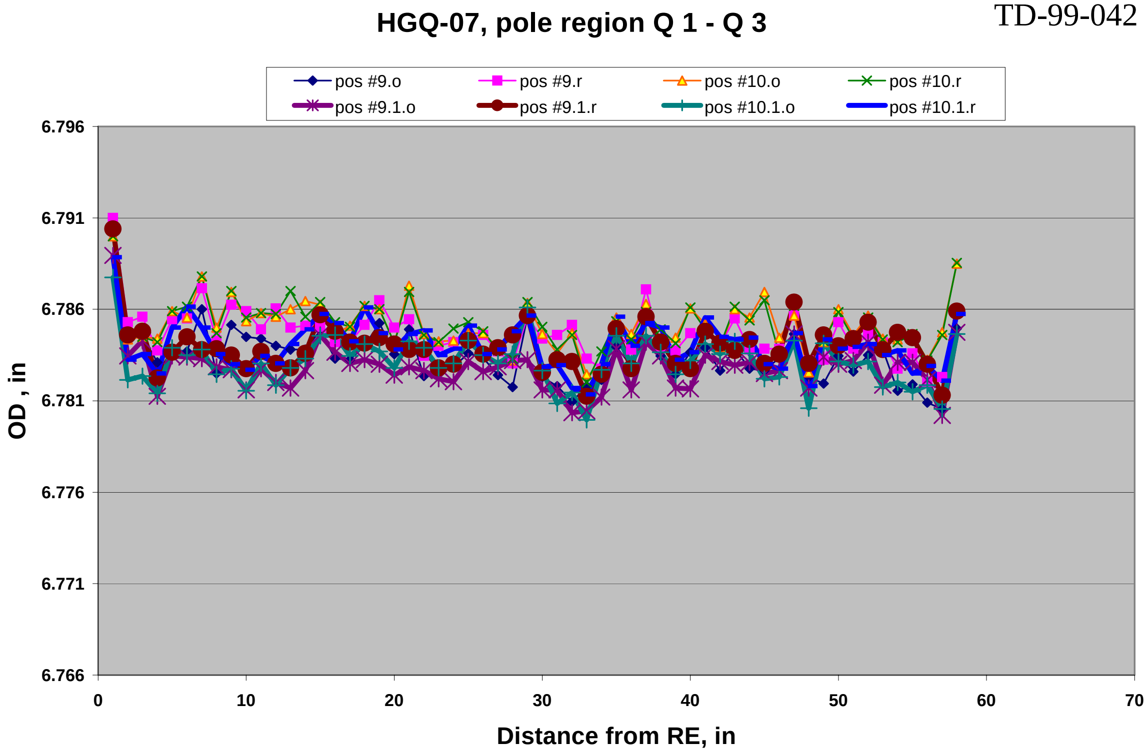


Figure 5.4.3 Collared coil deflections at pole region, pos#9,10.

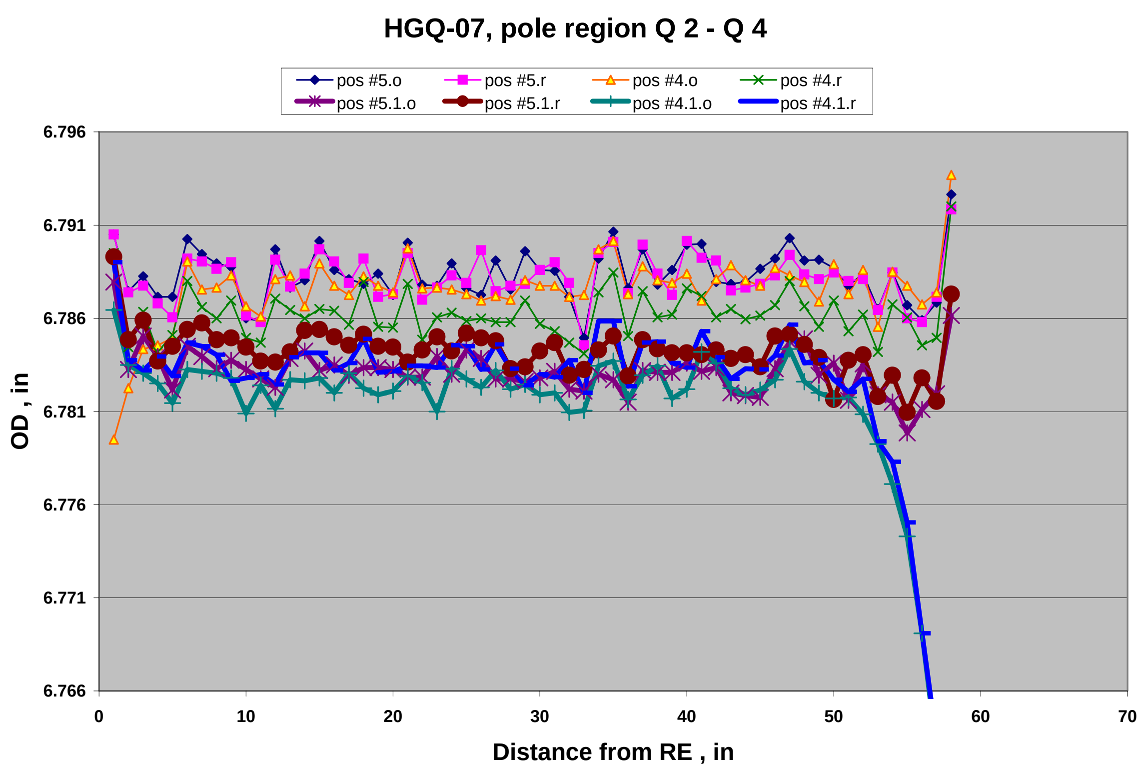


Figure 5.4.4 Collared coil deflections at pole region, pos#4,5.

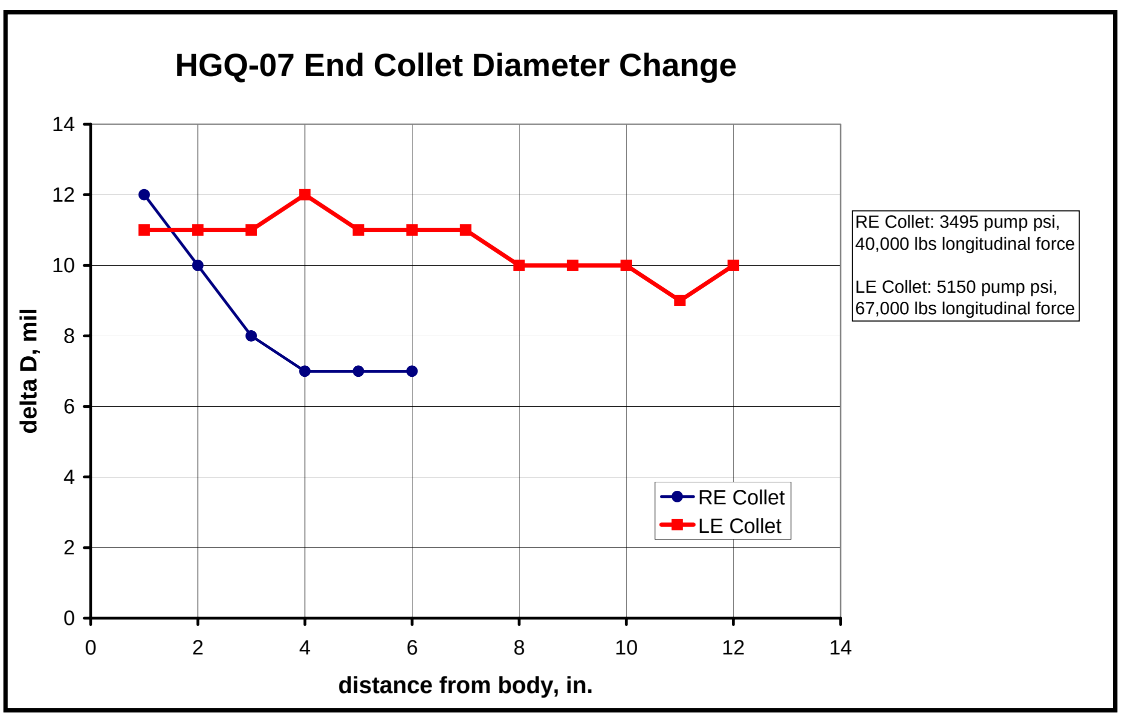
6.0 End Clamps

6.1 Installation Procedure

HGQ-07 has end cans at both LE and RE. The LE can is 9.833 inch and RE can is 5.194 inch long for HGQ-07. G-11 filler cones were used. Fuji film tests were performed before final installation. The results of the Fuji film readings showed that there is a uniform radial pressure distribution from the transition region to the end-saddle for both LE and RE. During the Fuji film tests at the LE, a turn to turn short between the first and second turn from the pole was detected while putting the end can on. The resistance measurements showed the short as one turn voltage drop. A visual inspection was conducted in order to locate the short spot. Voltage tap measurements showed that the short occurred in inner coil HGQi-054. The collared coil assembly was disassembled and the inner coil was replaced with the spare one. HGQ-07 was reassembled and re-collared. After the collared coil assembly was completed, the same amount of radial shimming of the end can were done with respect to the Fuji film test conducted earlier and the end cans were finally installed successfully.

6.2 Measurements and Shimming

The medium range Fuji film thickness is 4 mil and the Fuji film readings were taken without removing any designed ground insulation layer. The pi-tape measurements and film readings showed desired results. It was then decided to increase the thickness of radial ground insulation surrounding the outer coil by 3 mil at both ends from the



original design. The radial deflection of the aluminum end can according pi-tape measurements is shown below: (target diameter change from FEA, was 10 ~ 12 mil)

Fig 6.2.1: Aluminum End Can Radial Deflection

7.0 Yoke and Skinning

7.1 Assembly Configuration

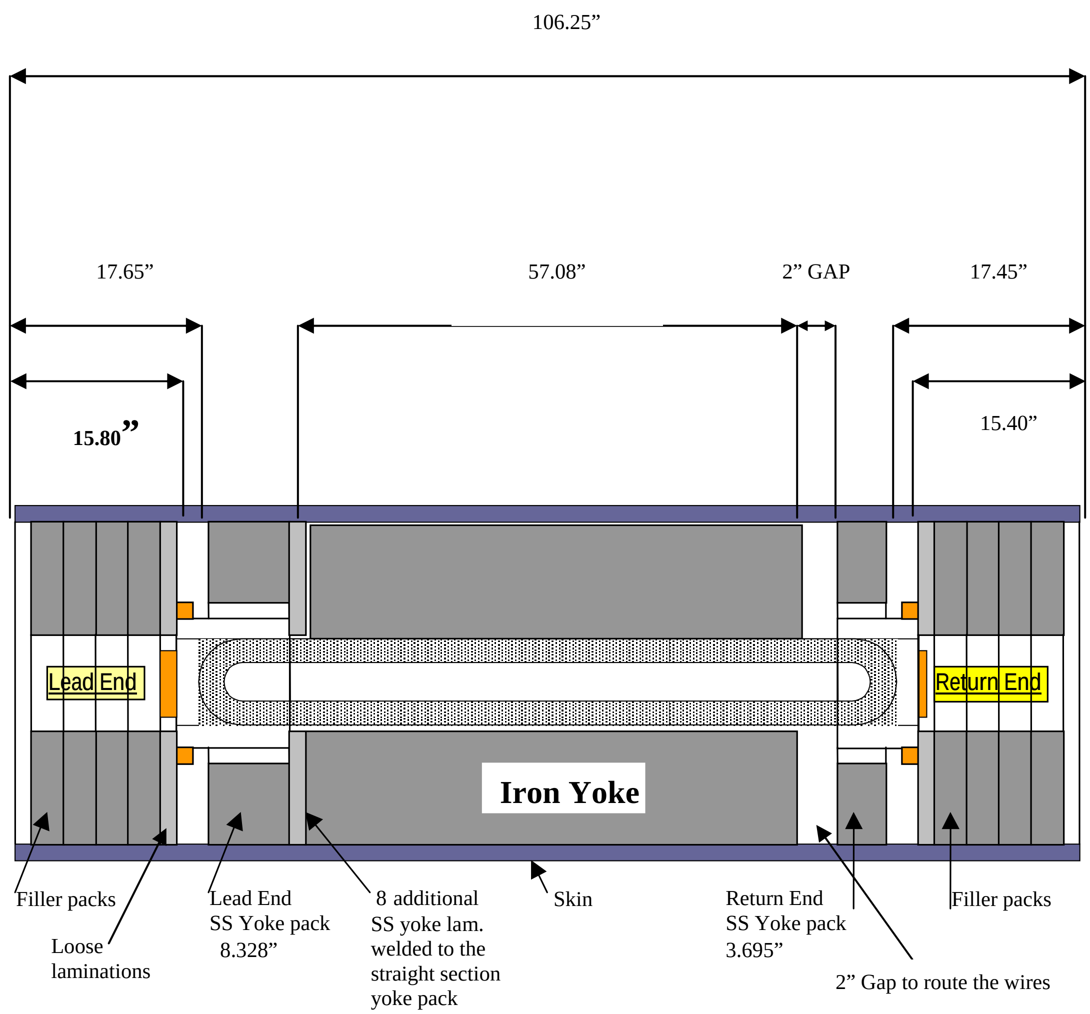


Fig 7.1.1: HGQ-07 Yoke Assembly Configuration

All lamination packs were fusion welded longitudinally in 7 places (5 welds on outer surface and 2 welds on inner surface). Instead of 2 loose and 2 welded stainless steel laminations that were usually added to the lead end side of straight section yoke pack, 8 stainless steel laminations were welded to the lead end side of the straight section yoke pack for HGQ-07. Stainless steel modified yoke laminations were used for RE and LE. These laminations were modified at the pole with EDM to fit over the LE and RE can. The above figure shows the length and the layout of the yoke laminations during assembly.

7.2 Welding

The skin alignment key was 24 mm wide for HGQ-07. The weld prep of the skin and skin alignment keys was modified from V to J groove to optimize the weld penetration specs. Because the volume of the weld prep increased, the amount of filler passes necessary to fill the groove was also increased from 2 filler passes to 4.

The 24-mm wide skin alignment key leaves a gap of 1.75 mm between the yoke and the skin. The magnet was compressed at 600 PSI during welding. The magnet was compressed in the contact tooling with a hydraulic pressure of 600 PSI corresponded to force about 8000 lbs. (3600 kg) per pusher or 16000 lbs./ft (23700 kg/meter) of magnet length. A pressure above 500 PSI must be applied to completely collapse the springs in the wheel units of the bottom tooling.

There was a consistent twist problem in all the previous HGQ welded cold masses. Before the welding of HGQ-07 cold mass, a mechanical model was welded and some experiments were conducted to eliminate the twist. It was found out that the welding torch carriers were not moving with the same speed. The south trail torches were moving almost 70% faster than north ones. This was causing an earlier welding at the south edge compared to north edge and it was introducing a clockwise twist (looking from LE) to all the previous cold masses. The north trail torches were forward offset by 2 inches to solve this problem.

After each pass of welding, the cold mass was taken out from the contact tooling and the twist was measured with the twist-measuring device to monitor the effect of the each weld pass on twist.

After each passes, the distance between the top and bottom pushers was measured from both the north and south side of the press all along the length of the magnet. The goal of these measurements is to monitor the shrinkage of the skin during welding. The total shrinkage does not have to be over 1.75 mm, if it does there is a probability that the yoke pack laminations can buckle by the excessive shrinkage forces introduced by the skin.

The below graph shows these results:

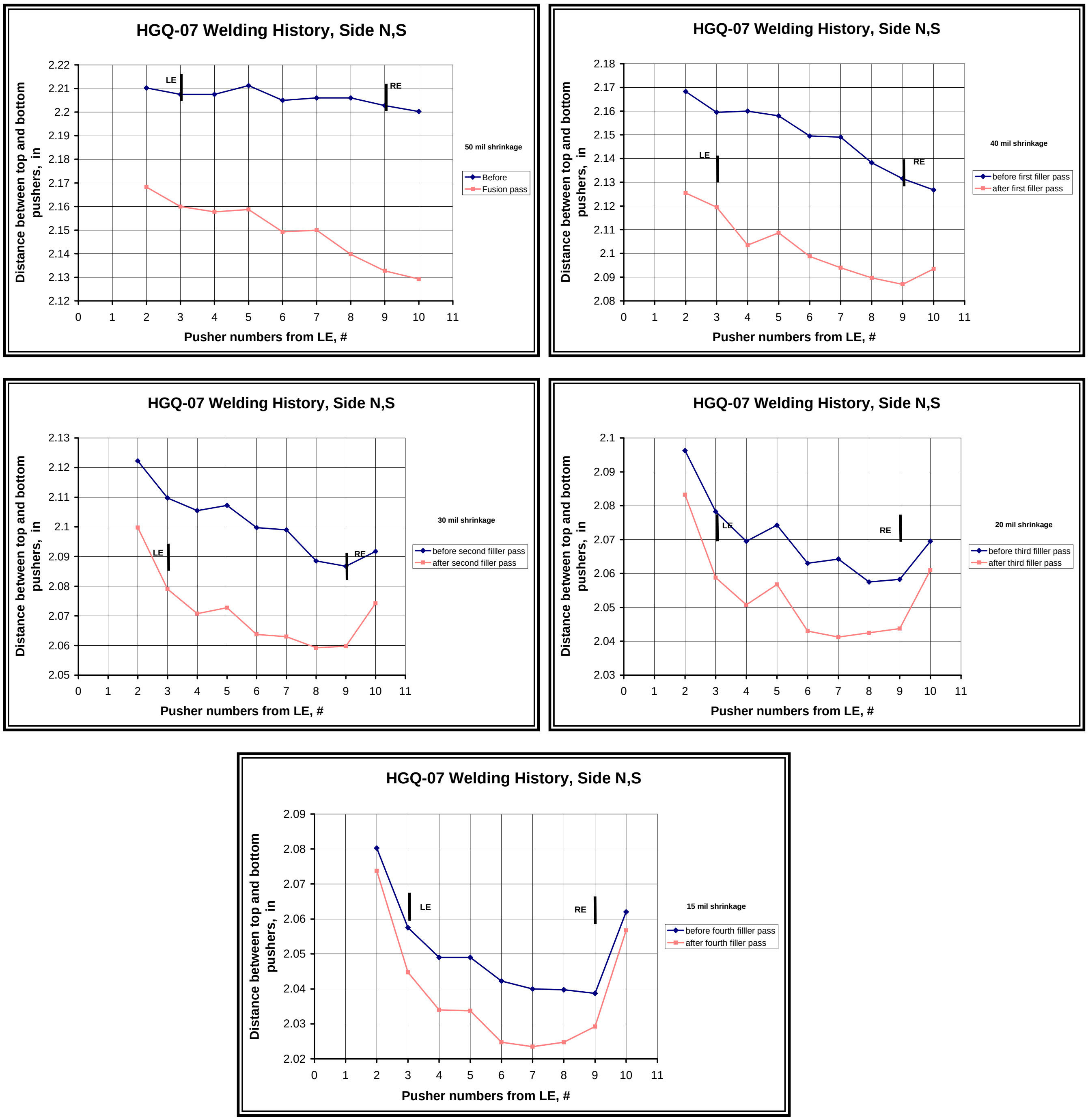


Fig 7.2.1: Weld Shrinkage for HGQ-07 with 24 mm key

The first pass was a fusion and consecutively fourth filler passes were applied. It took more filler passes than HGQ-06 and HGQ-05 to fill the weld prep with the new designed J groove. After the required depth of weld reached (25 mil under the flat edges of the key), the welding is completed. The total shrinkage was measured 15 mil over the design gap, but no visual buckling was observed on the yoke pack laminations.

After the welding was completed, the magnet was transported back to IB3 from ICB. The skin was cut to the exact length. After the routing of instrumentation wires were completed, the end plates were welded. The RE end plate was modified with small channels around the cooling holes to accommodate the instrumentation wires for the RE axial preload bolts.

7.3 OD and Twist Measurements

The skin OD measurements were taken at different angles after the end plate welding. The following graph shows the results of this measurement:

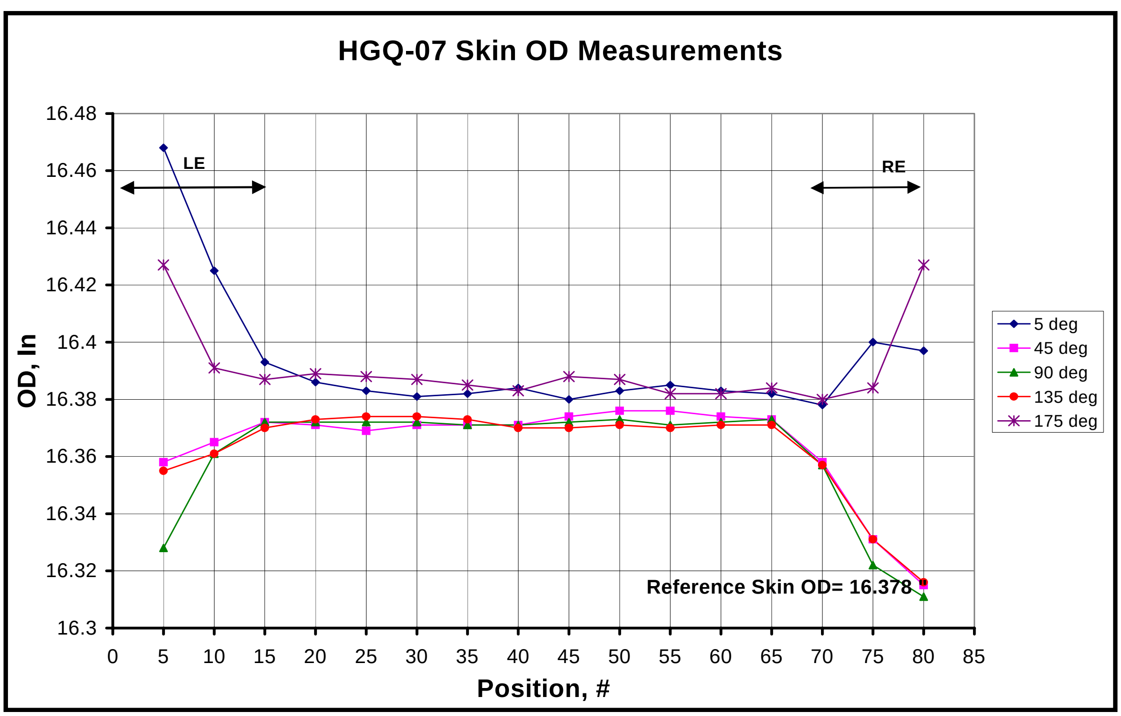


Fig 7.3.1: Skin outer diameter according to micrometer measurements taken at different angular positions between skin alignment keys

The twist was measured after the fusion and each filler pass in the contact tooling with the twist-measuring device. Before the welding started, the alignment group checked the straightness of the cold mass in the contact tooling when the press was energized. It is found out that there was no significant problem in the contact tooling which can cause a twist to the cold mass. The offset of the torches was kept same for each passes. The twist measurements conducted in the contact tooling did not show any major twist.

The twist in the cold-mass assembly after welding the skin and the end plates was measured with a height gauge and twist-measuring device on a granite table at IB3 to check the accuracy of the measurements done in the contact tooling. The twist is measured as 0.18 milli-radian per meter in the straight section of the magnet. The allowable twist for HGQ Cold Mass has to be less than 0.3 milli-radian per meter. The twist in HGQ-01 was 4.67 milli-radian per meter, for HGQ-02 it was 0.6 milli-radian per meter, for HGQ-03 it was 1.0 milli-radian per meter, for HGQ-05 it was measured as 0.9 milli-radian per meter and 0.95 milli-radian per meter for HGQ-06. The direction of the twist is same in all the five magnets and is clockwise looking from LE to RE. The below graphs show the height gauge measurements and respective twist measurements with height gauge and twist measuring device in milli-radians.

The twist problem seems to be solved with the offset technique of the torches for the moment. The technique will be rechecked one more time with the next magnet which will be HGQ-08.

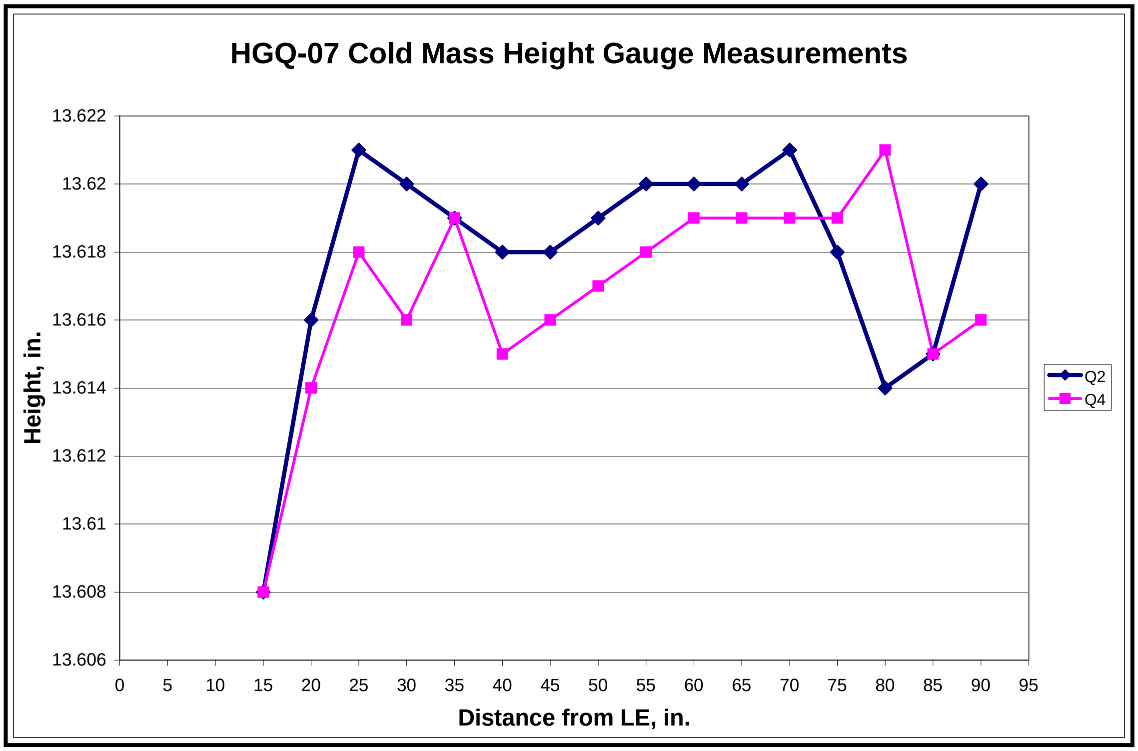


Fig 7.3.2: Height Gauge Measurements taken in Quadrant 2 and 4 for HGQ-07

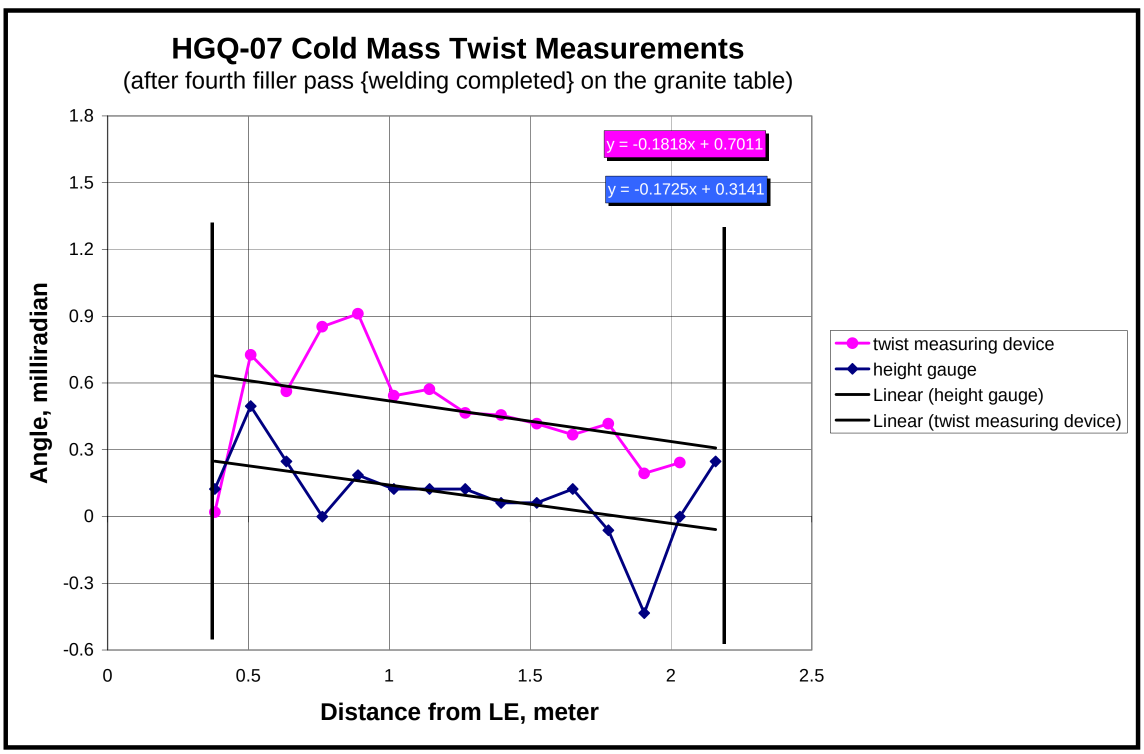


Fig 7.3.3: HGQ-07 Cold Mass Assembly Twist Measurements

7.4 Axial Loading (Bullets & Bolts)

The axial support system of the magnet is shown below:

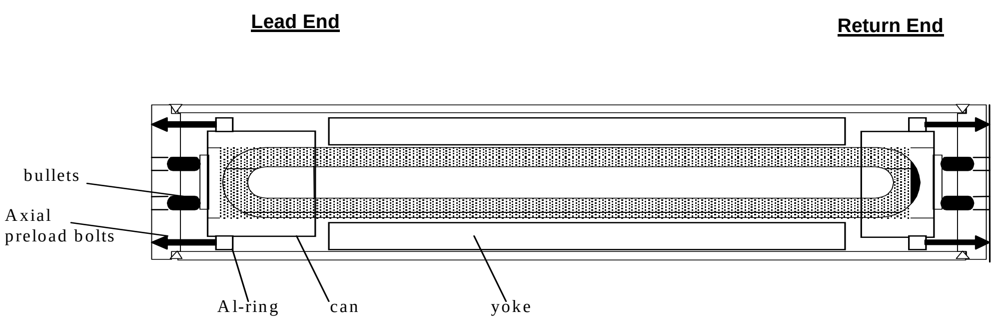


Fig 7.4.1: Axial Support of the Cold Mass Assembly

The end load has been applied by touching the bullets to the solid pusher plate, then tightening the bolts. The gaps between coil end-saddles and pusher plate was filled by "green putty". The bolts were instrumented to measure the force during loading, as were the bullets. Bullets and Bolts were warm and cold calibrated. It is decided to test HGQ-07 first and second thermal-cycle without any axial load. The goal of this is to evaluate the effect of axial loading to quench performance of the cold mass. The third thermal-cycle will be tested with axial loading. The bolts and bullets were installed to the magnet. The LE bolts and bullets were hand tightened. The RE bolts and bullets were loose. The magnet has to be taken out of the Dewar at MTF and the axial loading for the third thermal-cycle has to be completed as HGQ-06 loading procedure.

8.0 Final Assembly

8.1 Quadrant Splices

HGQ07 is the second magnet to be completed with double lead quadrant splices. All coils on HGQ07 have two leads per quadrant extending from the end, one being the usual coil lead and the other consisting of cable made with copper only strands, to be used as a stabilizer. All previous magnets had only single leads, except HGQ06. Parts on the end that enclose the leads required some revisions to accept the double layers of cable. The new configuration of the double lead quadrant splices can be found in the assembly drawing MD-344925. The splice soldering tooling was also modified to accommodate four cables and the solder thickness.

The double lead design has one complication. When the splice is made, it is necessary that the two coil leads be soldered directly to each other, with the stabilizer (copper only) leads on the outside, as shown in Figure 8.1.1. This occurs naturally in two of the three quadrants to be spliced. In one of the splices, however, as the leads extend out of the magnet and are placed together, the stabilizer from one of the coils is sandwiched between the two coil leads. This problem was solved by cutting the stabilizer just before the splice and reversing its position, as shown in Figure 8.1.2.

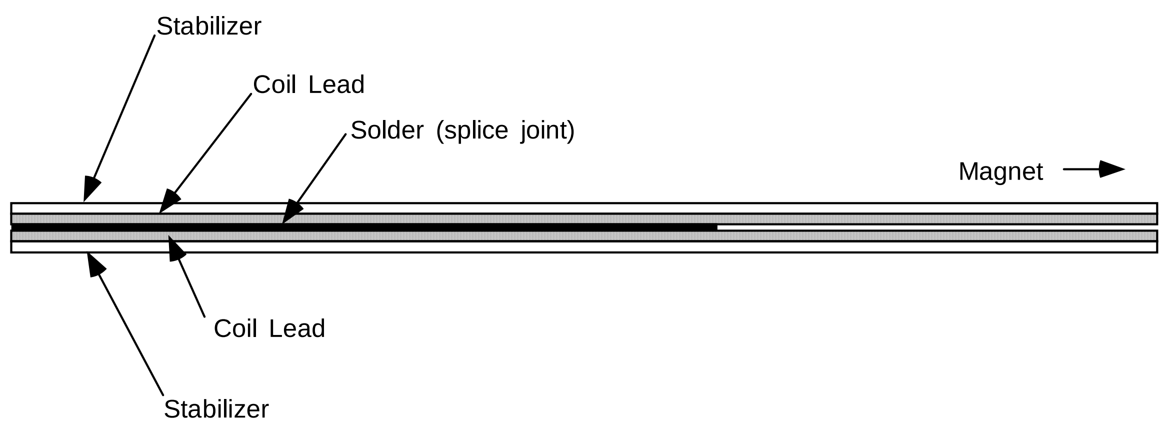


Fig. 8.1.1

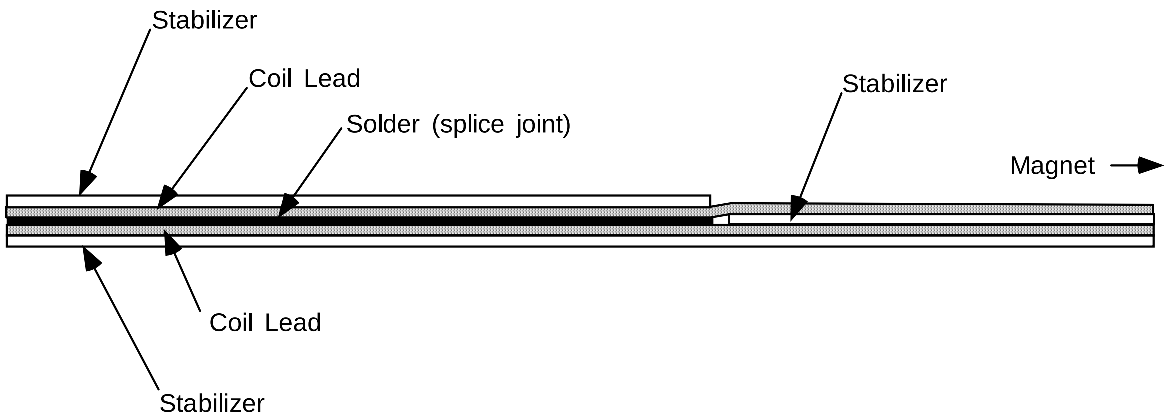


Fig. 8.1.2

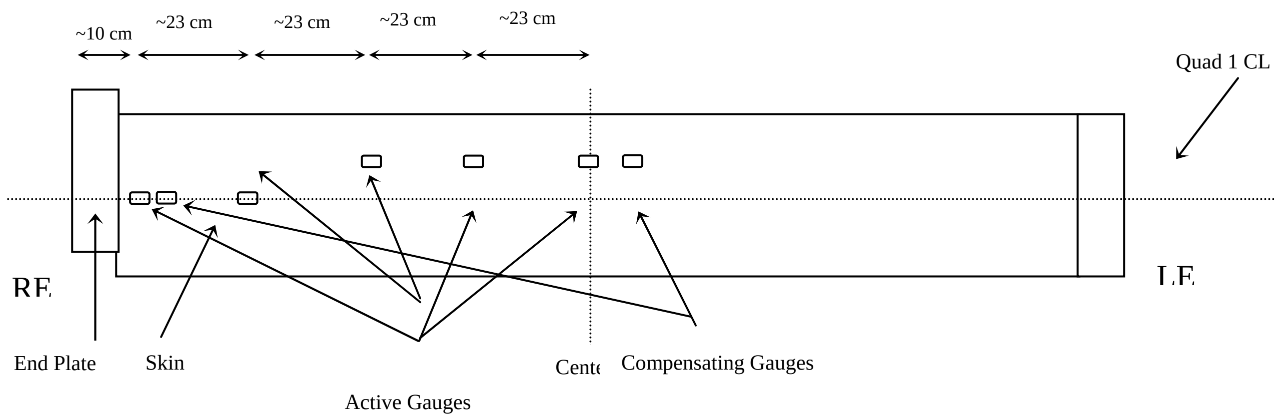
The first experience with the double lead quadrant splices was with HGQ-06. The cable insulation during splicing was repeated same way to eliminate of a short during the bending of the cables for the splice. The quadrant splices were installed successfully to HGQ-07.

8.2 Skin Gauges

A total of 10 active strain gauges (Stk. # WK-09-250BG-350) were mounted in a longitudinal orientation along the length of the magnet. They were spaced approximately 23 cm apart, beginning about 10 cm from the end of the return end endplate, up to the cold mass center. Five were placed along the centerline of quadrant 1, and five were placed on a line 45 degrees from the centerline of quadrant 1, between quadrants 1 & 2. Compensating gauges were placed in a longitudinal orientation adjacent to the return end and centerline active gauges, co-linear with the active gauges.

In total, 14 strain gauges were placed on the shell, 10 active and 4 compensating. All were oriented so that their grids are parallel to the longitudinal axis of the cold mass.

See the diagram below:



8.2.1: Skin Gauge Layout (Side view of the skin)

Sensor	VMTF name	Z-position	Sensor	VMTF name
HGQSk#77 :	SkAcL010-1	10 cm	HGQSk#84 :	SkAcL010-2
HGQSk#78 :	SkAcL033-1	33 cm	HGQSk#85 :	SkAcL033-2
HGQSk#79 :	SkAcL056-1	56 cm	HGQSk#86 :	SkAcL056-2
HGQSk#80 :	SkAcL079-1	79 cm	HGQSk#87 :	SkAcL079-2
HGQSk#81 :	SkAcL104-1	104 cm	HGQSk#88 :	SkAcL104-2
HGQSk#82 :	SkCoL010-1	10 cm	HGQSk#89 :	SkCoL010-2
HGQSk#83 :	SkCoL104-1	104 cm	HGQSk#90 :	SkCoL104-2

On Q1 centerline

45 degrees from Q1 towardsQ2

Sensor #	Orientation	Type	z-position (cm from RE endplate)	θ-position (degrees from Q1 centerline)	VMTF name
HGQSk#77	Longitudinal	Active	10	0	SkAcL010-1
HGQSk#78	Longitudinal	Active	33	0	SkAcL033-1
HGQSk#79	Longitudinal	Active	56	0	SkAcL056-1
HGQSk#80	Longitudinal	Active	79	0	SkAcL079-1
HGQSk#81	Longitudinal	Active	104	0	SkAcL104-1
HGQSk#82	Longitudinal	Comp	10	0	SkCoL010-1
HGQSk#83	Longitudinal	Comp	104	0	SkCoL104-1
HGQSk#84	Longitudinal	Active	10	45	SkAcL010-2
HGQSk#85	Longitudinal	Active	33	45	SkAcL033-2
HGQSk#86	Longitudinal	Active	56	45	SkAcL056-2
HGQSk#87	Longitudinal	Active	79	45	SkAcL079-2
HGQSk#88	Longitudinal	Active	104	45	SkAcL104-2
HGQSk#89	Longitudinal	Comp	10	45	SkCoL010-2
HGQSk#90	Longitudinal	Comp	104	45	SkCoL104-2

Table 8.2.1: HGQ-07 Shell Gauges

8.3 Final Electricals

HGQ-07 was hi-potted coil to ground, heater to ground and heater to coil at 1500 V. Leakage is required to be less than 0.5 μA at 1500 V. All the coils and the outer strip heaters passed the hi-pot test.
The final electrical data collected before shipping to MTF:

	Resistance ohm	**Ls μ H**	**Q**
Q1 - inner	.0855	179.618	1.93
Q1 - outer	.1084	313.802	2.19
Q2 - inner	.0853	179.980	1.89
Q2 - outer	.1085	315.135	2.11
Q3 - inner	.0856	178.618	2.08
Q3 - outer	.1084	313.141	2.18
Q4 - inner	.0853	179.813	1.98
Q4 - outer	.1093	315.175	2.19

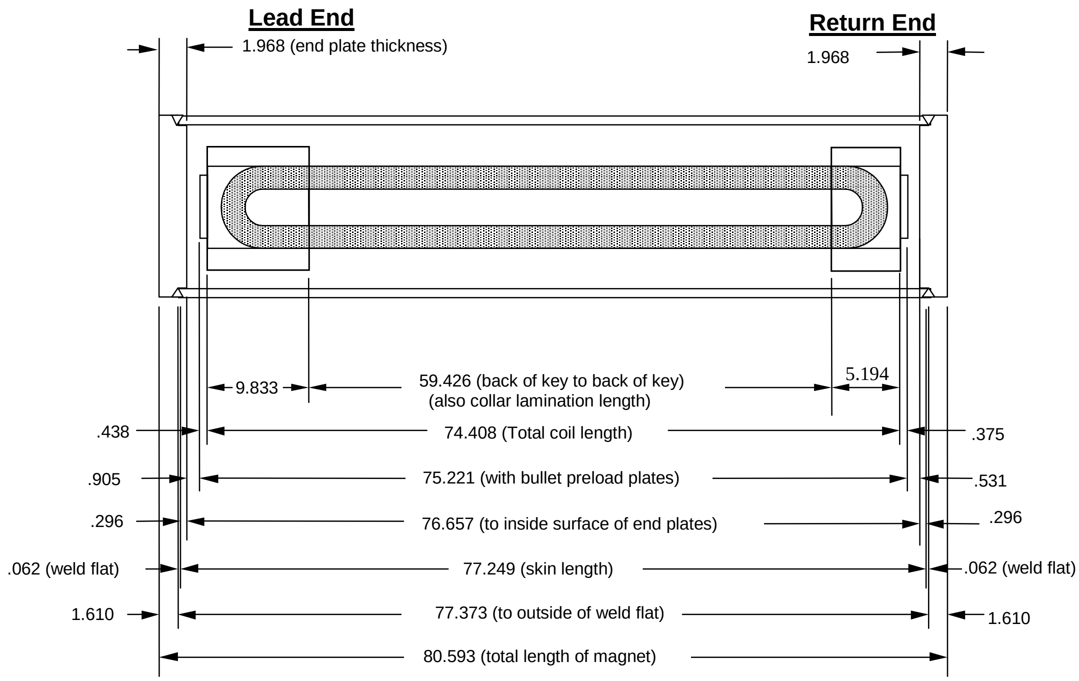
Q1 – Quadrant total	.1937	819.608	3.22
Q2 – Quadrant total	.1940	823.564	3.13
Q3 – Quadrant total	.1935	819.124	3.20
Q4 – Quadrant total	.1445	825.529	3.19
	Resistance ohm	**Ls MH**	**Q**
Magnet Total	0.7814	3.4560	2.92

Table 8.3.1: Magnet Resistance, L and Q measurements.

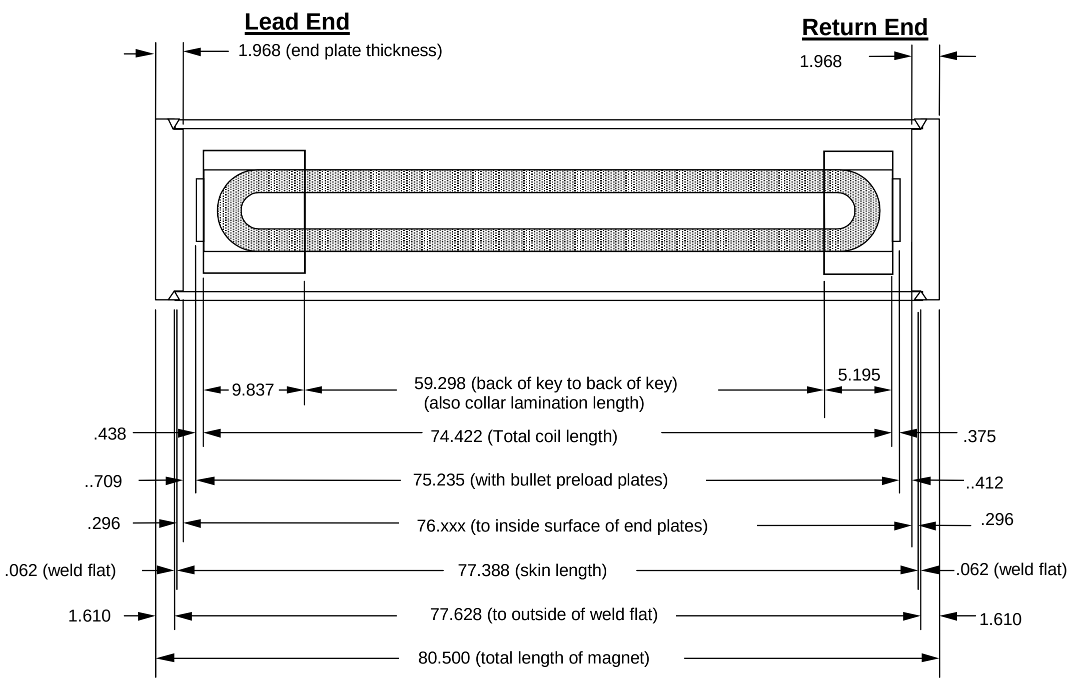
Heater	Resistance ohm
Q-1/2 - outer	2.875
Q-2/3 – outer	3.136
Q-3/4 – outer	3.054
Q-4/1 - outer	2.885

Table 8.3.2: Heater resistance measurements

8.4 Mechanical Measurements



These are the design dimensions for HGQ07



These are the measured dimensions for HGQ07

APPENDIX - I

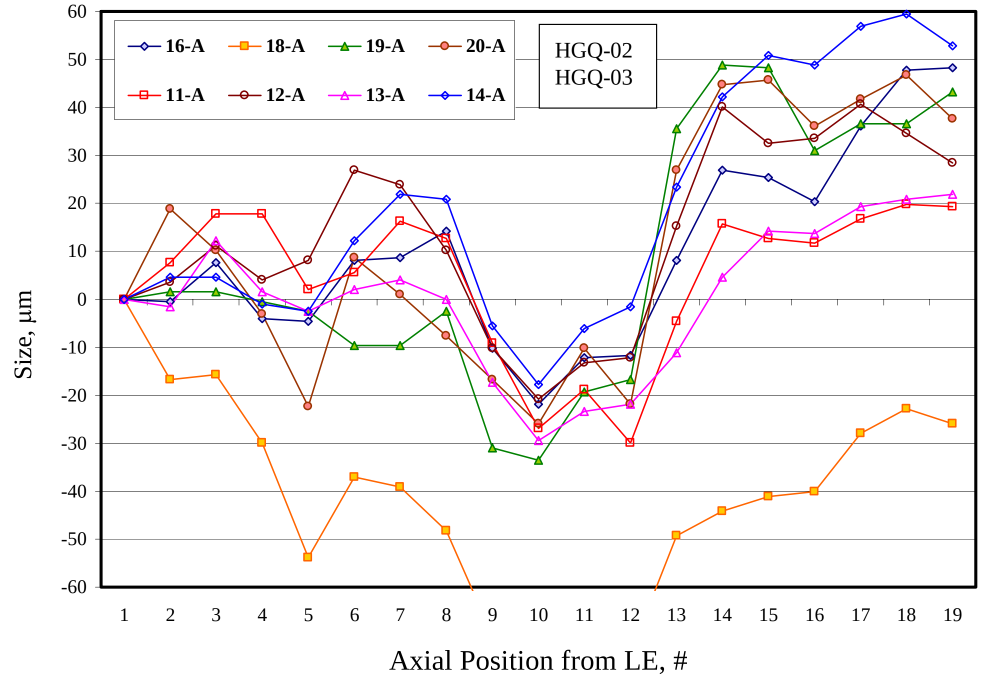


Figure A1: *Variation of size on SIDE A for coils used in HGQ-02 and HGQ-03.*

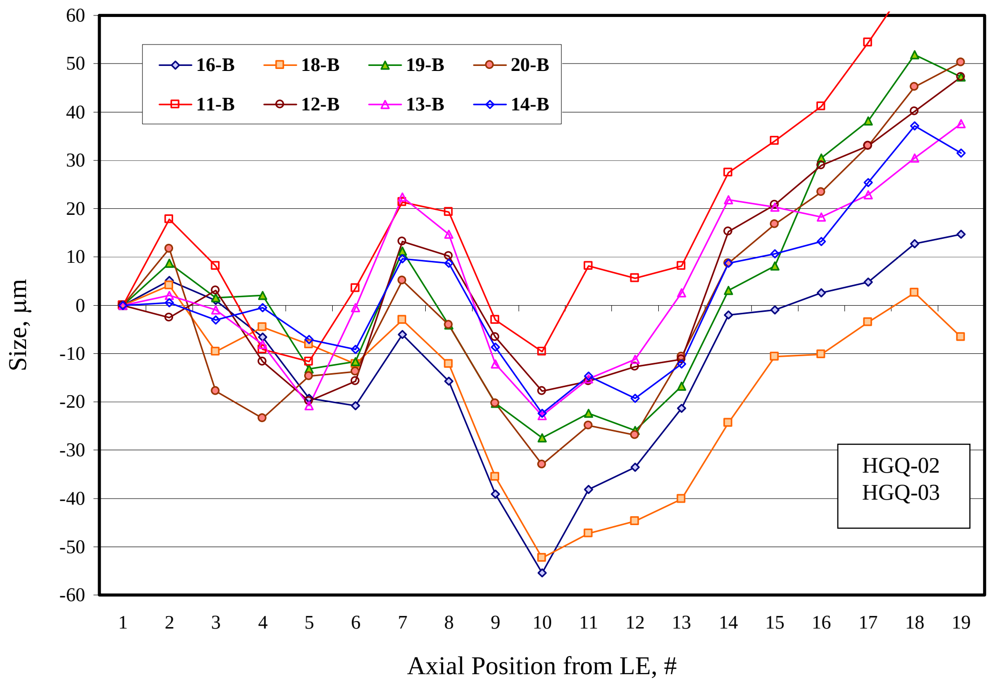


Figure A2: *Variation of size on SIDE B for coils used in HGQ-02 and HGQ-03.*

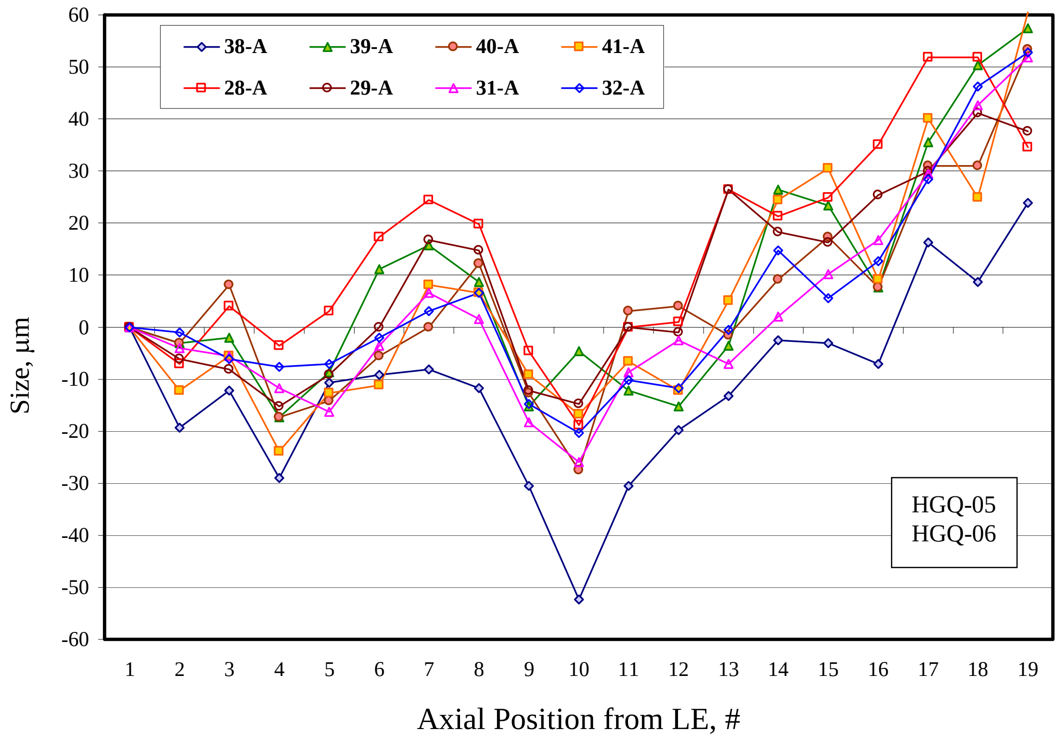


Figure A3: *Variation of size on SIDE A for coils used in HGQ-05 and HGQ-06.*

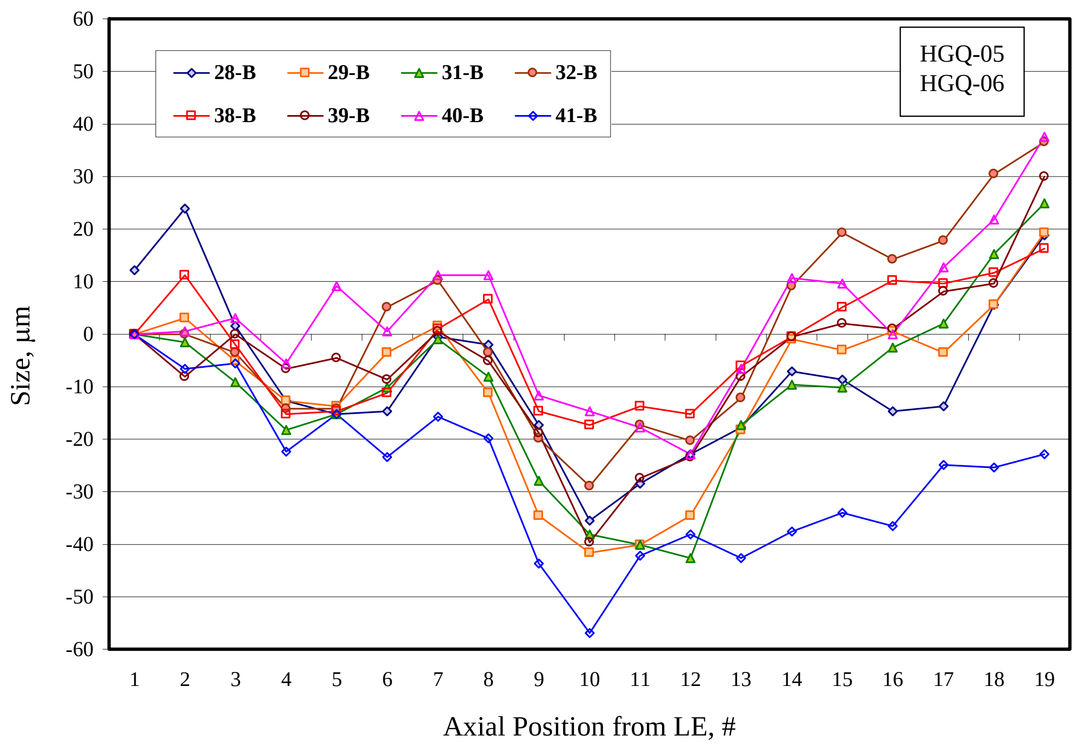


Figure A4: *Variation of size on SIDE B for coils used in HGQ-05 and HGQ-06*