TD 98-044

HGQ-02 production report

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7. Appendix (exist as a hard copy)

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1. Introduction

HGQ-02 is the second of several 2-meter long model IR quadrupole magnets to be built at FNAL in support of the LHC project at CERN. The baseline design is described in the HGQ Conceptual Design Report. This report is issued in conjunction with the HGQ-02 production summary TD-98-01X and consists of data collected during magnet fabrication and production tests.

2. Superconducting Cable.

2.1 Cable parameters.

Tables 1,2,3 show the mechanical and electrical parameters for the HGQ-02 inner and outer cables.

Table 1. Cable Mechanical Parameters

Parameter	Unit	Inner cable by design	Inner cable for HGQ-02	Outer cable by design	Outer cable for HGQ-02
Radial width, bare	mm	**15.4**	**15.3975**	**15.4**	**15.3951**
Minor edge, bare	mm	**1.326**		**1.054**	
Major edge, bare	mm	**1.587**		**1.238**	
Midthickness, bare	mm	**1.457**	**1.4559**	**1.146**	**1.1456**
Keystone angle,	deg	**0.990**	**1.048**	**0.690**	**0.702**
Cable packing factor		0.91		0.91	
Number of strands		38	38	46	46
Strand diameter	mm	0.808		0.648	
Pitch direction		right	right	left	left
Pitch length	mm	114		101.6	

Table 2. Cable Electrical Parameters

Parameter	Unit	Inner cable	Outer cable
R (295 K)	μohm	15.80	18.7

R (10 K)	μohm	0.36	0.55
RRR		44	34
Cu / Sc		1.33	1.71

Table 3. Cable test data

T = 4.22 K	Unit	Inner cable			Outer cable		
B	T	6.00	7.00	8.00	6.00	7.00	8.00
Ic	kA	19.531	14.453	9.375	12.538	9.341	8.144
Jc	A/mm^2	2312	1717	1114	2226	1659	1091

The cable inspection data are included in Appendix.

2.2. Cable cleaning.

Both inner and outer cables have been cleaned before insulating.
We are, temporarily, cleaning the cable with **Axarel 6100** in the SSC cleaning module.

2.3. Cable and Wedge Insulation

Cable insulation parameters are summarized in Table 4.

Table 4. HGQ-02 cable insulation parameters.

Parameter	Inner cable	Outer cable
Number of wraps	2	2
Inner wrap: -material -adhesive -wrap structure -thickness	 Kapton tape 25 μm×9.5 mm None Spiral wrap with 50% overlap 50 μm	 Kapton tape 25 μm×9.5 mm None Spiral wrap with 50% overlap 50 μm
Outer wrap: -material	 Kapton tape 50 μm ×9.5 mm	 Kapton tape 50 μm ×9.5 mm

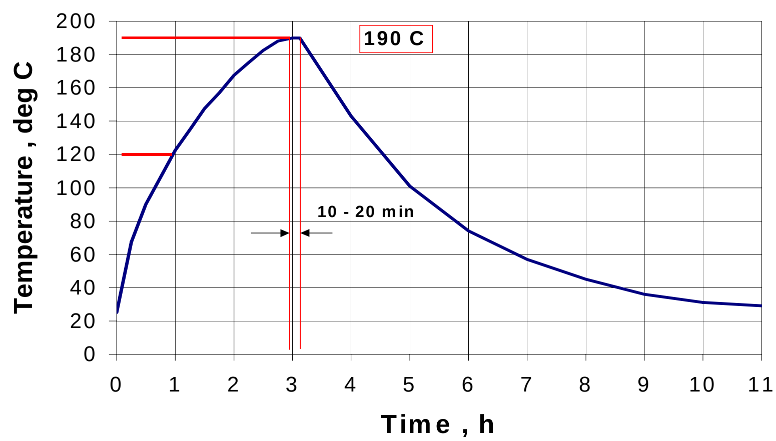
-adhesive -wrap structure -thickness	Liquid polyimide (“QI” modified) Spiral wrap with 2 mm gap 50 μm	Liquid polyimide (“QI” modified) Spiral wrap without gap 50 μm
Total undeformed thickness	100 μm	100 μm
Cable insulation adhesive	“QIX” polyimide	“QIX” polyimide

3. Inner and Outer Coils

Six inner and **five outer** coils had been wound, cured and measured as potential coils for HGQ-02. Only the four inner and four outer coils used in HGQ-02 are included in this report.

3.1 Winding and curing.

The nominal winding tension of 36.28 kG [80 lbs] was used for all turns on both inner and outer coils.
Two wedges, one per octant, were used in each outer and inner coil. 3mm gaps were placed longitudinally between end spacers and wedges on each end. All outer coil wedges consisted of a single piece on both sides. Some inner coils had a single piece on one side and two pieces, butted together longitudinally on the other. Some inner coils had the two piece wedge configuration on both sides (as noted on traveler).
All coils, both inner and outer, are cured in mold cavities, which are designed to have the precise cross section of the finished after they are assembled with the final design preload applied. Cavity sizes are, however, shimmed to adjust azimuthal coil size. Azimuthal coil sizes are changed to achieve the desired preload in the assembled magnet, based on prior empirical evidence.
Curing mold cavity azimuthal shim was 508 μm [0.020 in] for inner coils and 0.0 μm for outer coils with respect to design size. The coils are cured under radial and azimuthal pressure. The curing cycle was identical for both inner and outer coils. Temperature and pressure regimes are shown below in Fig. 1,2.



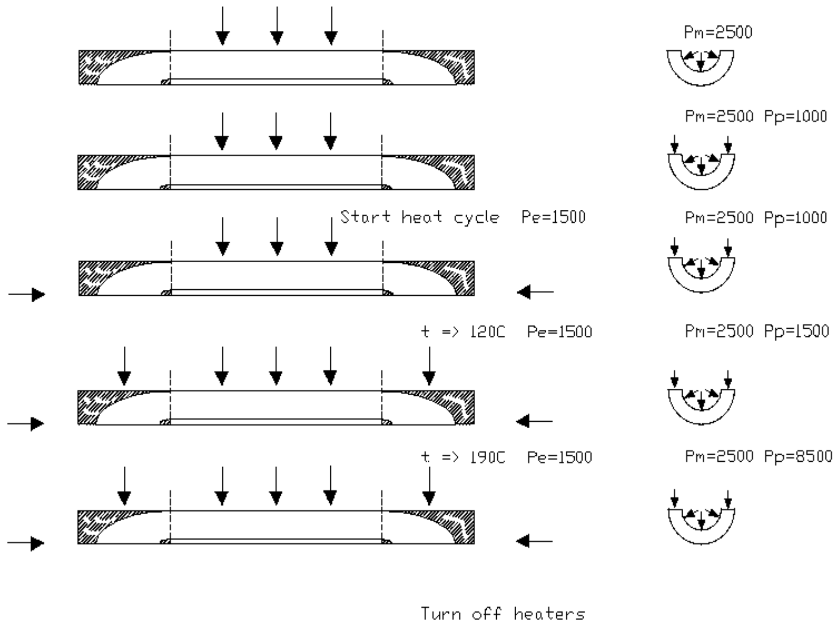


Figure 1. Coil curing thermal cycle.

Figure 2. Loading scheme and sequence during coil curing.

Pm-mandrel force, lbs per linear inch; Pp-platen pressure , coil psi ;
Pe-end force, lbs

3.2 Coil longitudinal change after curing.

After curing and removing the winding pole block the coil length change. Coil regions where the measurements have been taken are shown in Fig.3. Data are reported in Table 4.

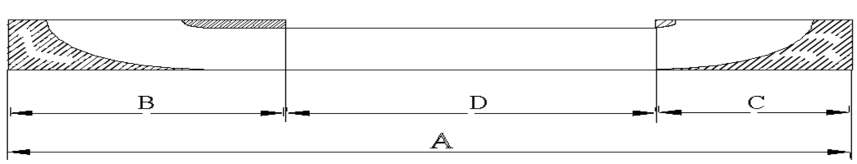


Figure 3. Coil measured positions.

Table 4 Length changes after coil removed from mandrel.

	Inner coils	Outer coils
Meas.	Avg. Change	Avg. Change
Changing C RE	.023	.019
Changing D	-.061	-.129
Changing B LE	.054	.079
Changing A	-.006	-.030

3.3 Copper stabilizer.

The copper stabilizer (a 1.5 mm thick piece of copper, the same width as the cable and 30 mm long) was soldered on the cable at lead end of coils after curing to protect cable from popping strands and collapsing during the magnet assembly process.

3.4 Coil size and modulus.

Azimuthal size measurements of the coils are taken at a range of pressures encompassing those, which the magnet will experience during operation. Specifically, the coils are measured at pressure of 55MPa, 70MPa, 83 MPa and 97 MPa (8000 psi, 10000 psi, 12000 psi and 14000 psi). The design pressure for inner and outer coils when cold and unpowered for HGQ-02 were 83 MPa (12000 psi) for both the inner and outer coils.

Table 5. Inner Coil body size and Modulus.

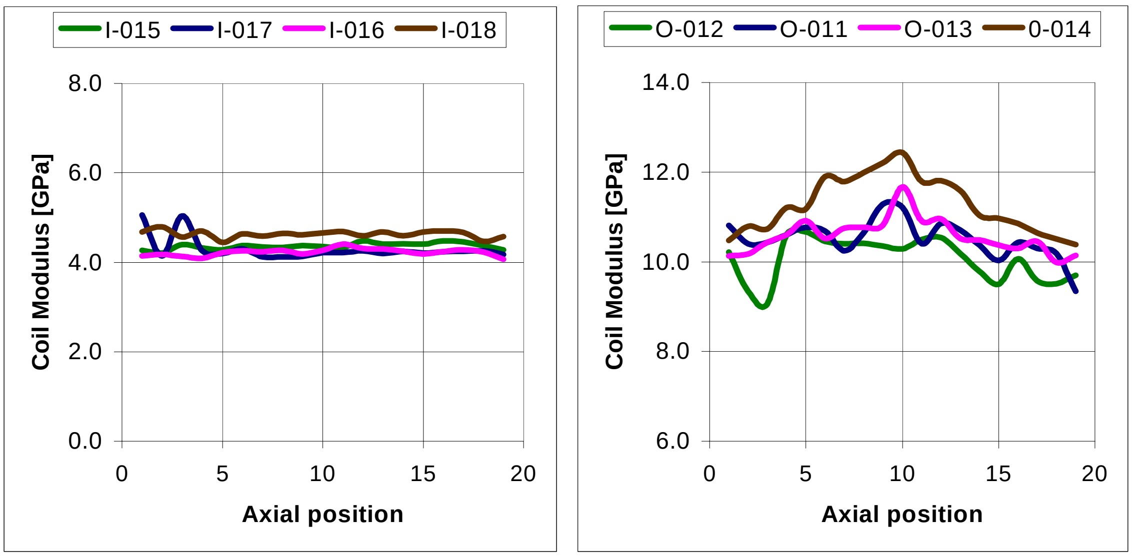
Coil	Coil average modulus [GPa] at pressure range 55-97 MPa		Coil size at 83 MPa coil pressure [μm]			
	Average	Stand. Div.	Side A	Stand. Div.	Side B	Stand. Div.
I-015	4.5	0.3	120	19	120	18
I-016	4.3	0.1	116	7	111	24
I-017	4.5	0.5	89	26	81	20
I-018	4.5	0.2	82	10	79	14

Table 6. Outer Coil body size and Modulus.

Coil	Coil average modulus [GPa] at pressure range 55-97 MPa		Coil size at 83 MPa coil pressure [μm]			
	Average	Stand. Div.	Side A	Stand. Div.	Side B	Stand. Div.
O-011	11.1	0.7	154	16	115	26

O-012	10.6	0.7	150	19	92	21
O-013	10.5	0.8	120	15	102	18
O-014	11.1	1.00	131	25	105	16

Coils are measured azimuthally in increments of 76.2 mm [3 in] along the straight section starting from the Lead End. Position #10 is in the middle of the coil straight section or coil body.
Coil modulus at these positions is shown in Fig. 5.



a. inner coils b. outer coils

Figure 5. Coil modulus along length.

Size measurements along inner and outer coils are shown in Figures 6 and 7.

A- side on which winding of, first turn begins, B- side which includes parting plane lead.

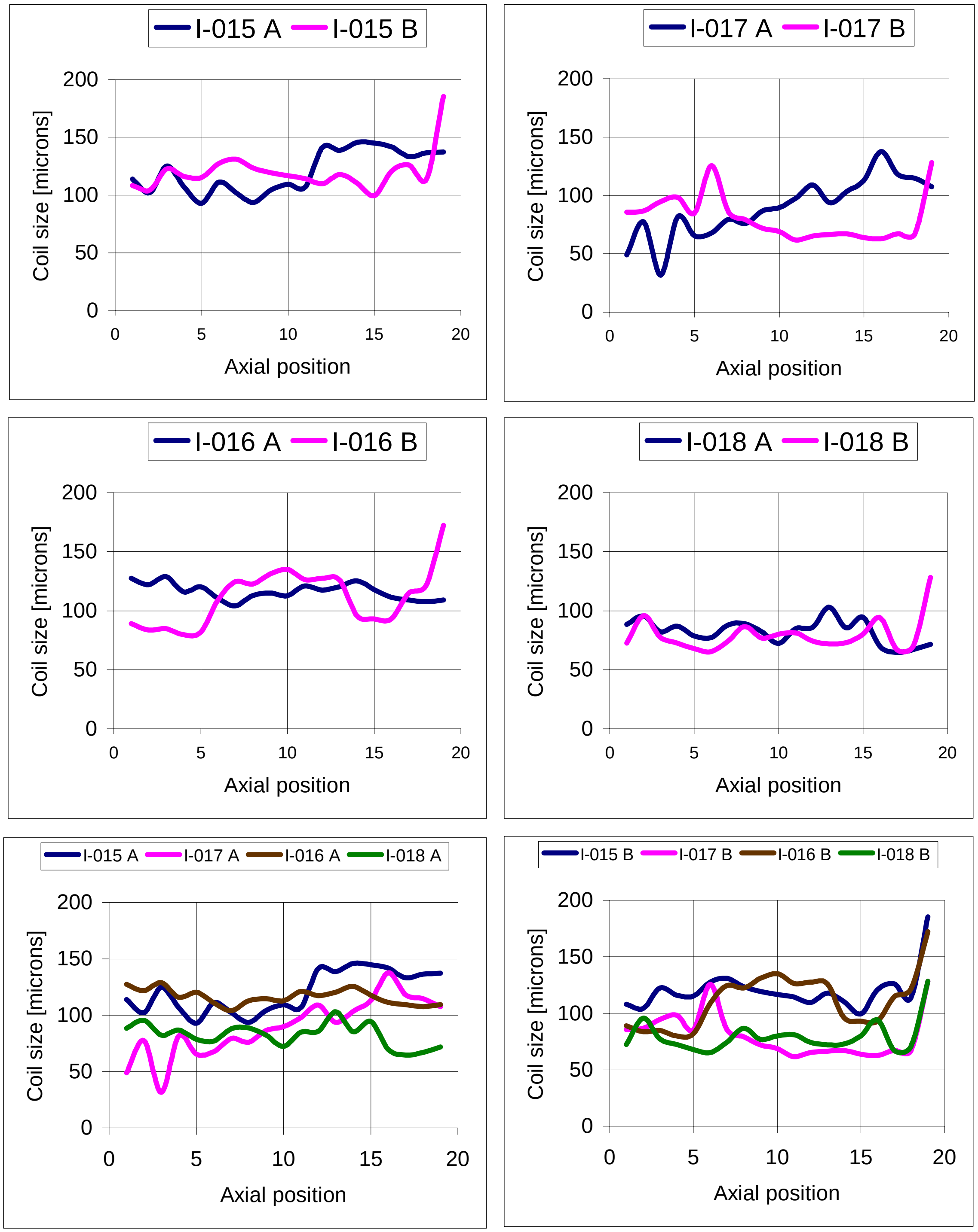


Figure 6. Inner coil azimuthal size along length.

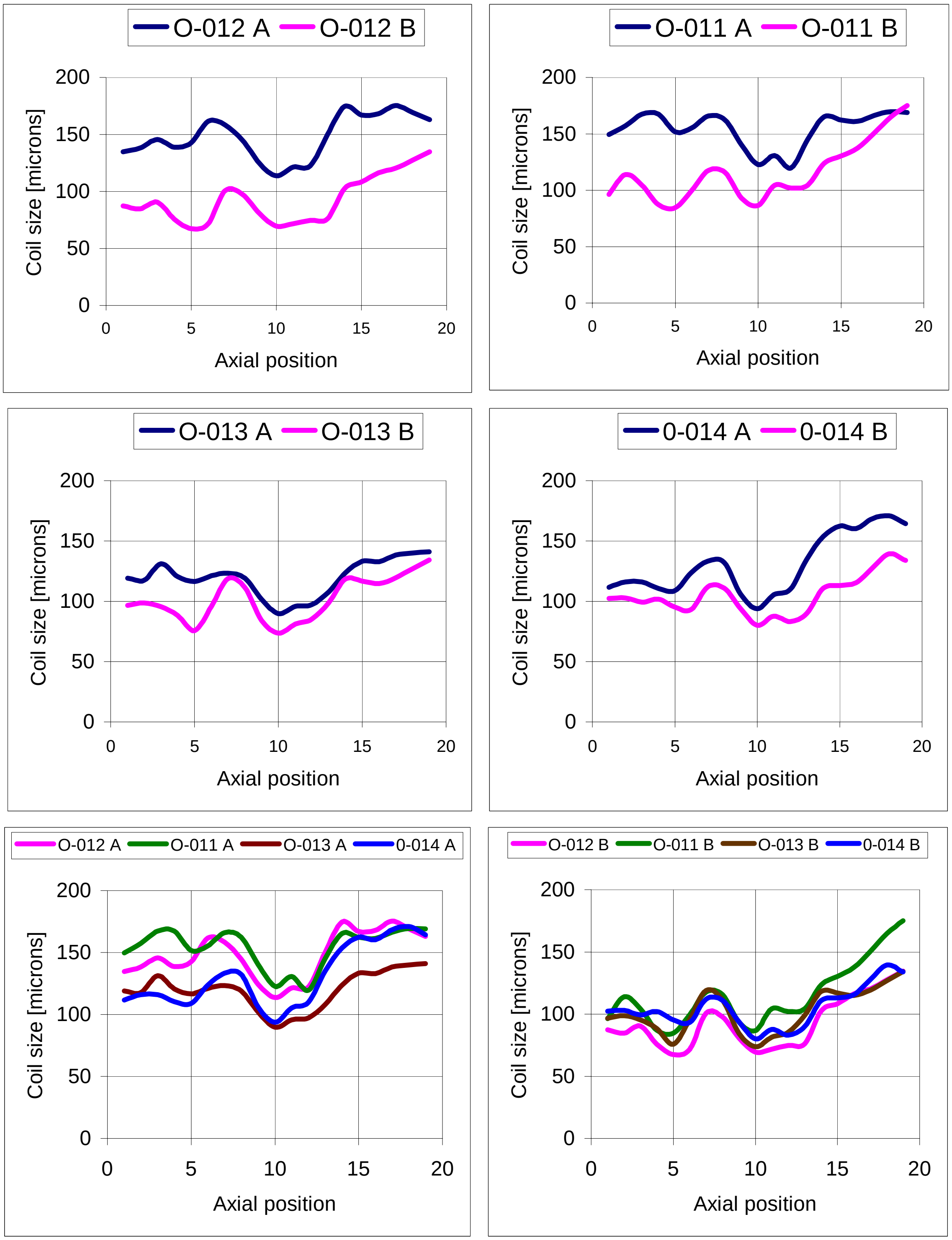


Figure 7. Inner coil azimuthal size along length.

The end fixture was designed to check electrically coil ends for turn-to-turn shorts at azimuthal pressures of 83 MPa (12000 psi). One inner coil (I-012) failed after this test.
This fixture was also used for coil azimuthal end measurements. The measured area is 152.4 mm [6 in]. Measured positions are shown in Fig. 8.

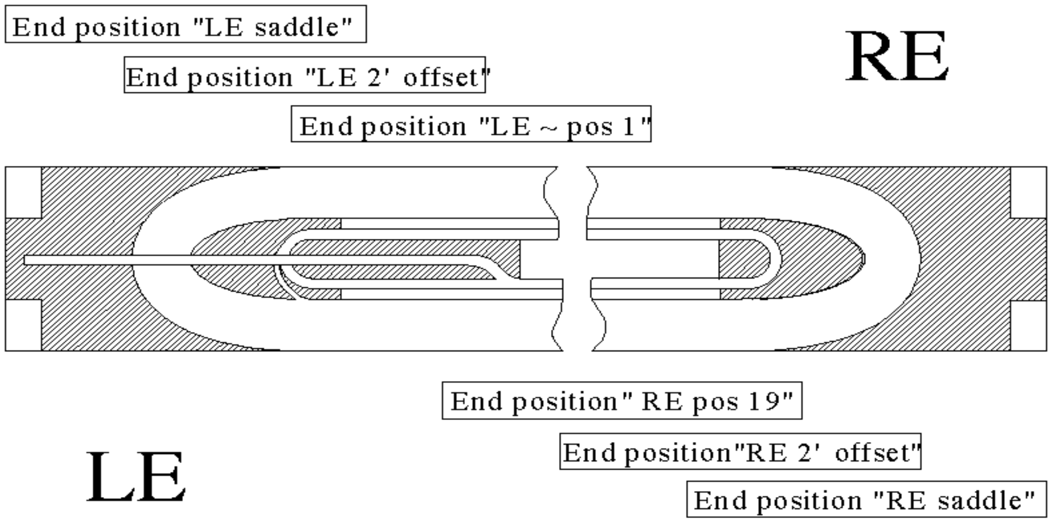


Figure 8. Measured position for end fixture.

Selected positions in the body region were measured with this fixture to "cross calibrate" it with the fixture used to measure the body. Fig. 9 shows the data from both measuring systems on one coil.

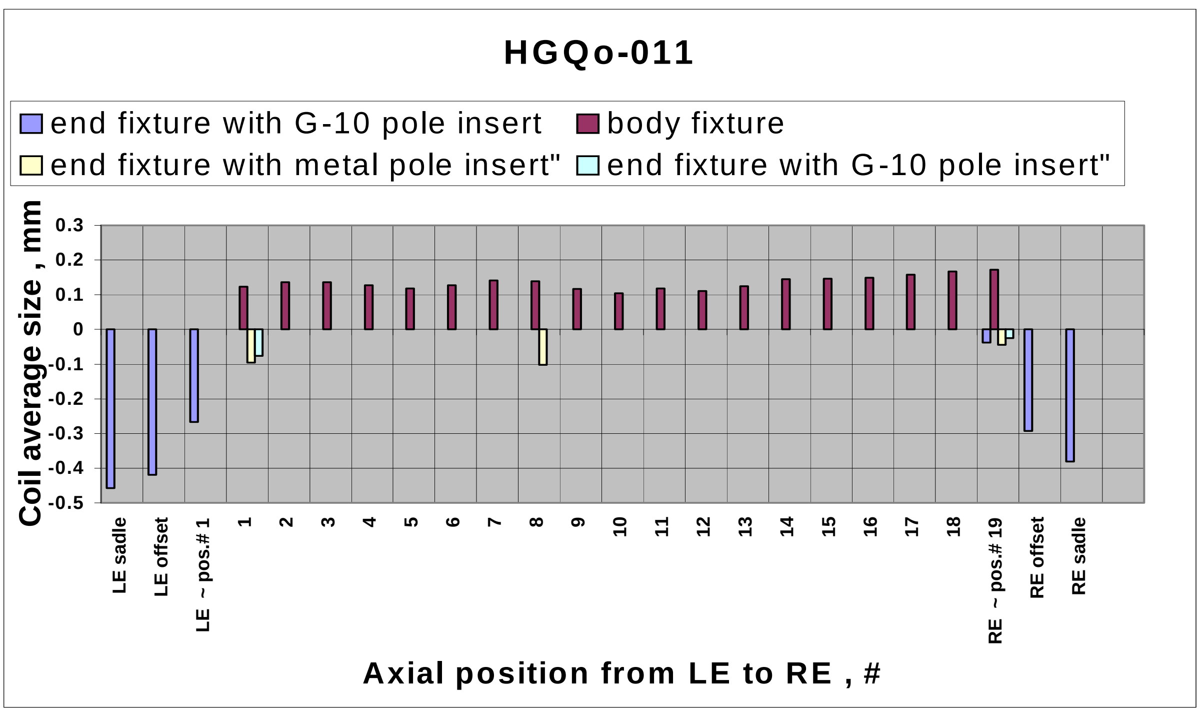


Figure 9. Measuring outer coil O-011 in different fixture.

Results of end measurements are plotted in Fig. 10,11 and summarized in Table 10,11 for inner and outer coils respectively.

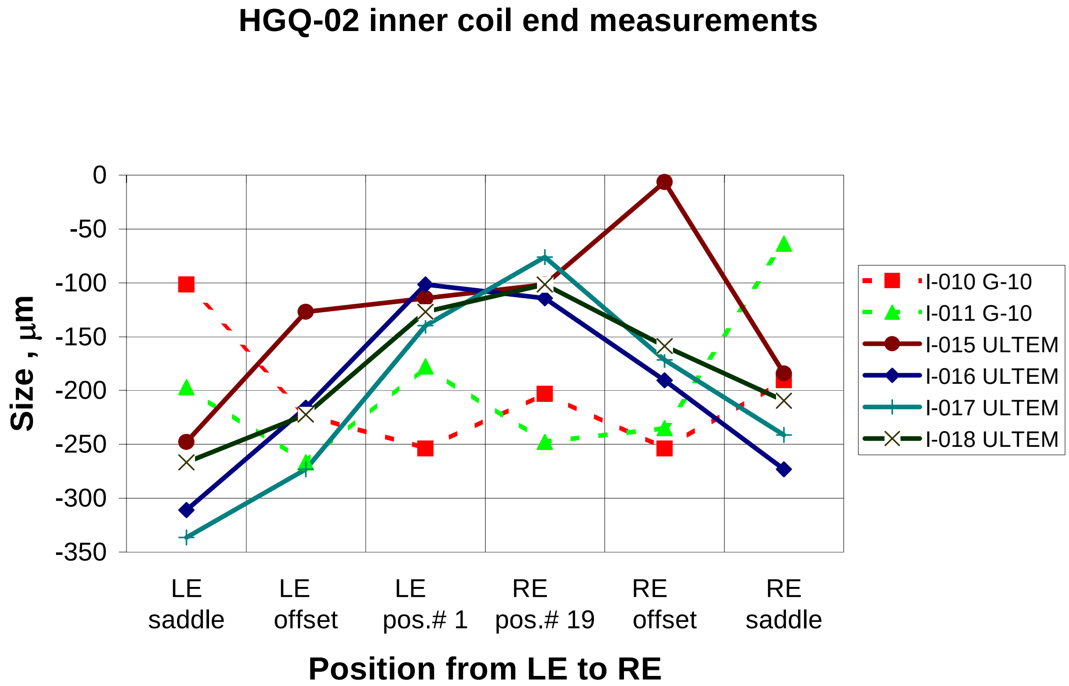


Figure 10.

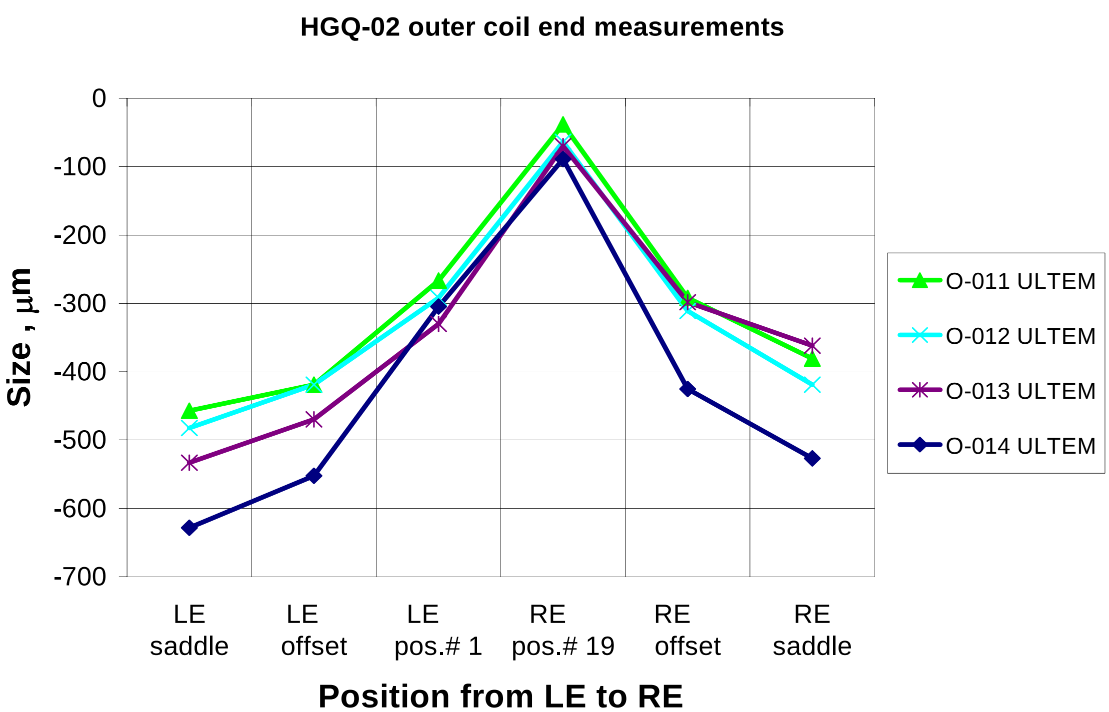


Figure 11.

Table 7. Inner coil End Size, μm

Coil #	LE saddle	LE offset	LE, Pos.#1	Body, Avg.	RE, pos.#19	RE offset	RE saddle
I-015	28	149	161	120	161	91	22
I-016	-56	39	153	114	141	65	-18
I-017	-142	-79	54	85	118	23	-47
I-018	-65	-21	75	81	100	43	-8

Table 8. Outer coil End Size, μm

Coil #	LE saddle	LE offset	LE, pos.#1	Body, Avg.	RE, pos.#19	RE offset	RE saddle
O-011	-247	-209	-57	135	172	-82	-171
O-012	-270	-206	-79	121	149	-98	-206
O-013	-326	-263	-123	111	138	-91	-155
O-014	-391	-314	-67	118	149	-187	-289

3.5 Visual inspection.

Adhesion of end parts to the cable is poor for all coils. The saddles come off easily and the other parts are not adhering well.

HGQi-015:

Broken shelf on Lead End and Return End.
on Lead End
Saddle hanging inside bore.
spacer and cable
Gap between spacer and coil turn on both ends.

End

HGQi-016:

Saddle hanging in bore

Large gap between

on both ends.
Shelf broken off Return

HGQi-017:

Broken shelf on both ends of coil.
ends
Saddle hanging down on Lead End at side A.
wire on

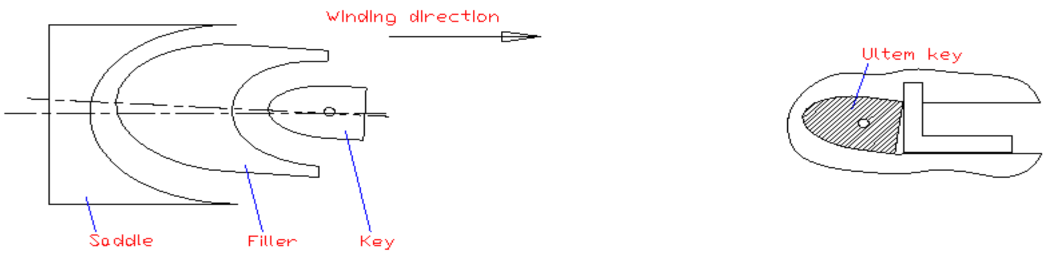
HGQi-018:

Broken shelves on both

Gap between spacer and

both ends.

All Ultem end spacers have to be held in correct axial position to avoid rotation during winding. Neither inner nor outer mandrel had holes for the purpose of holding down these parts. After curing, these spacers had moved out of position, causing geometrical and mechanical errors in coil ends as



shown in Figure 12.

Figure 12. Geometrical errors in coil ends.

End part adhesion continues to be a problem on polyimide /Ultem coils. Especially after end compression testing, saddles came off easily and other parts did not adhere well, making it difficult to assemble coils on the collaring mandrel. The saddle on outer coil O-010 was cracked during this test. The RE saddle on coil O-011 was reglued to the conductor block (on one side) using an end fixture and 5-minute epoxy. This was done without removing the saddle from the coil.

3.6 Spot heaters and voltage taps.

In order to measure quench propagation velocities, a total of 6 spot heaters were mounted onto certain coils. In order to separate effects due to end region, a total of 112 voltage taps were mounted near the end region of the coil in the collared region of the magnet. All electrical wires were located according to notes TD 97-027, TD 98-006 except for tap 1D which was placed at the middle of the Return End saddle.
A new procedure has been applied for tap installation to decrease the potential for shorts related to taps. The new procedure specifies that the

Kapton cable insulation be cut longitudinally at the center of the narrow edge of the cable, instead of scraped away. It also allows the remaining Kapton to be folded back, providing an insulating barrier so that solder is not likely to flow onto the next turn. All coils were tested twice in the end fixture, before and after voltage tap installation. No shorts due to voltage taps were discovered during the end compression tests.

The drawing numbers for voltage taps and heaters are 5520-MD-344511 (rev.B) and 5520-MD-344512 (rev.B).

4. Collared coil.

4.1 Preload adjustment.

Room temperature preload for HGQ-02 in the inner and outer layer ~ 83 MPa (12000 psi) corresponds to a coil azimuthal size of +375 μm for inner and +250 μm for outer coils. The inner coil size approximately +75 μm/+125 μm [+0.003 in/+0.005 in], so they had to be shimmed up ward by 300 μm /250 μm [0.012 in/0.010 in]. The outer coil size was +125 μm [+0.005 in], so they needed to be shimmed up ward by 125 μm [0.005 in]. In additional to the body, the end region shim had been calculated according to end measurements taken at position “offset” and “~ #1”. The 25 μm [0.001 in] for inner and the 75 μm [0.003 in] for outer end region had been added to each shim to compensate for the differential thermal contraction between stainless steel (collar) and Ultem (end spacer) pole coil blocks.

4.2 Shim plan.

All coils had been shimmed upward at the parting plane, uniformly across the coil from end-of-saddle to end-of-saddle. The shim plan is shown on plots and figures 13-18.

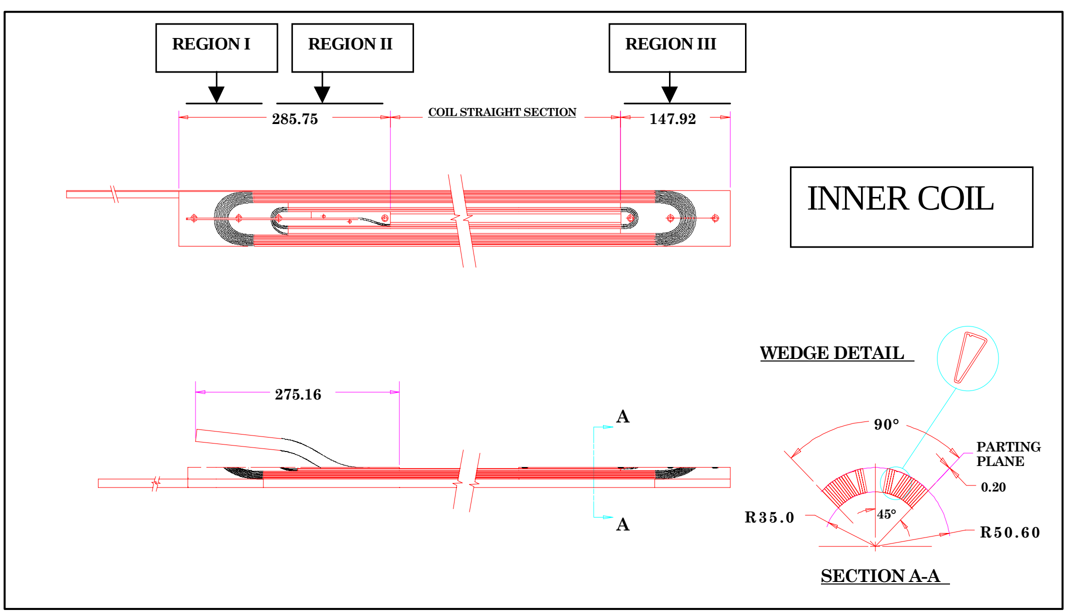


Figure 13. Inner coil body and three End Regions.

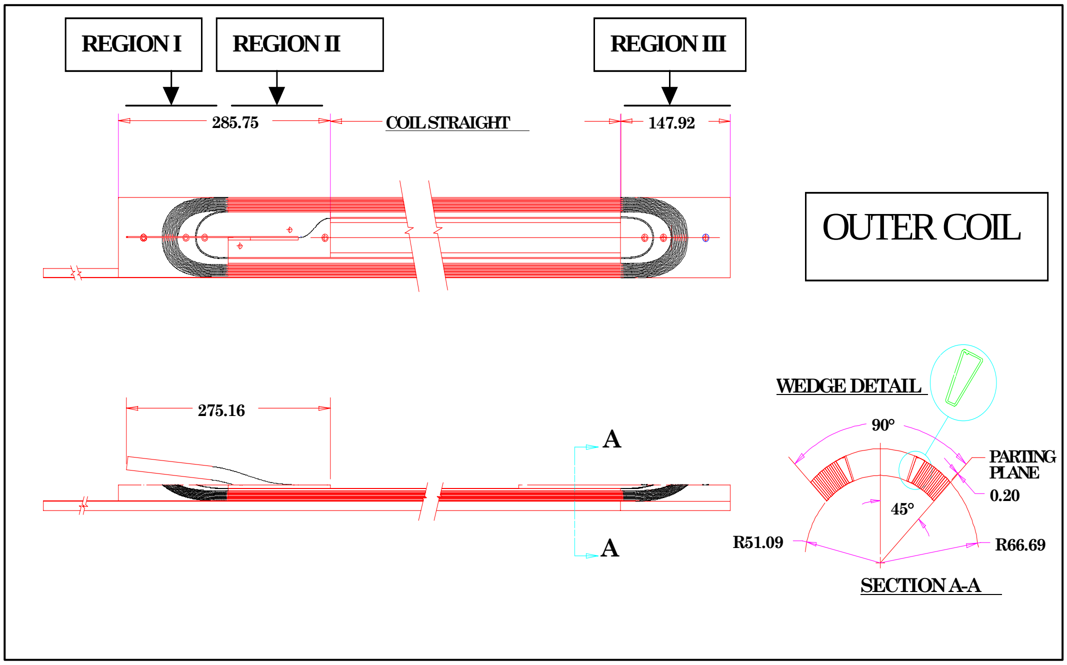


Figure 14. Outer coil body and three regions.

Table 8. HGQ-02 midplane shims, mil

		LE region I	LE region II	Body	RE region III
Inner coil	I-015	13=5+5+2+1	11=5+5+1	10=5+5	13=5+5+3
	I-017	15=5+5+2+2+1	13=5+5+2+1	12=5+5+2	15=5+5+2+3
	I-016	13=5+5+2+1	11=5+5+1	10=5+5	13=5+5+3
	I-018	15=5+5+2+2+1	13=5+5+2+1	12=5+5+2	15=5+5+2+3
Outer coil	O-012	22=5+5+5+5+2	17=5+5+5+2	5	17=5+5+5+2
	O-011	22=5+5+5+5+2	17=5+5+5+2	5	17=5+5+5+2
	O-013	22=5+5+5+5+2	17=5+5+5+2	5	17=5+5+5+2
	O-014	22=5+5+5+5+2	17=5+5+5+2	5	17=5+5+5+2

All extra shims are stepped, or “feathered”, in ½ inch increments at region border LE I-II, and in ¼ inch increments at region border Body-RE III and Body-LE II.

HGQ-02 Coil Placement and Shim Size.

Data: 2-18-98 R.Bossert/I.Novitski

Magnet Body

Looking from Lead to Return End

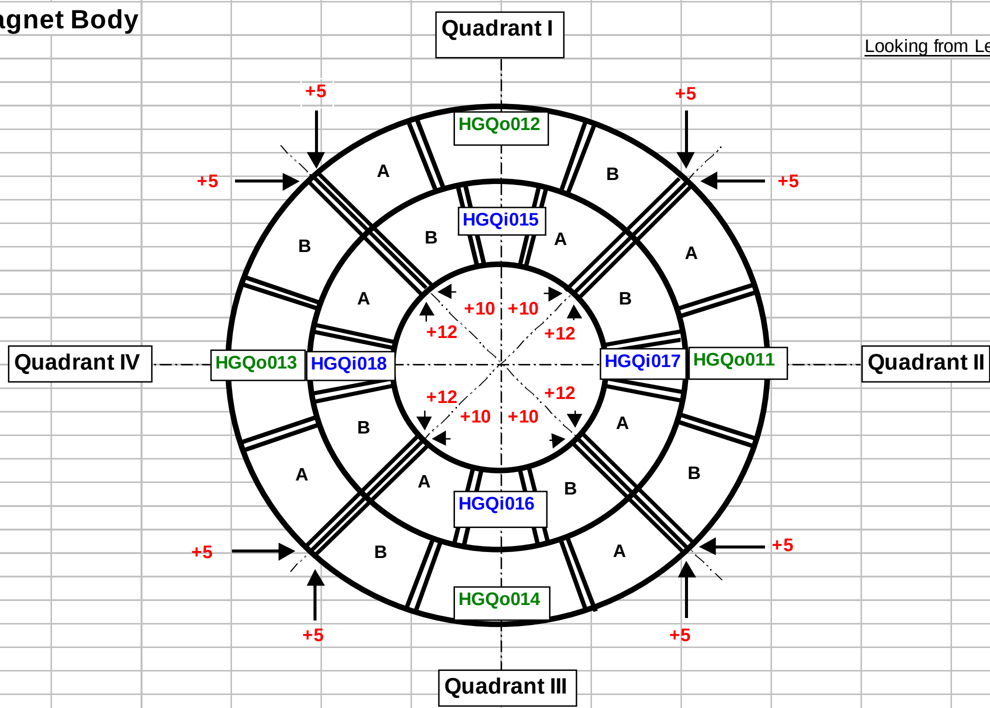
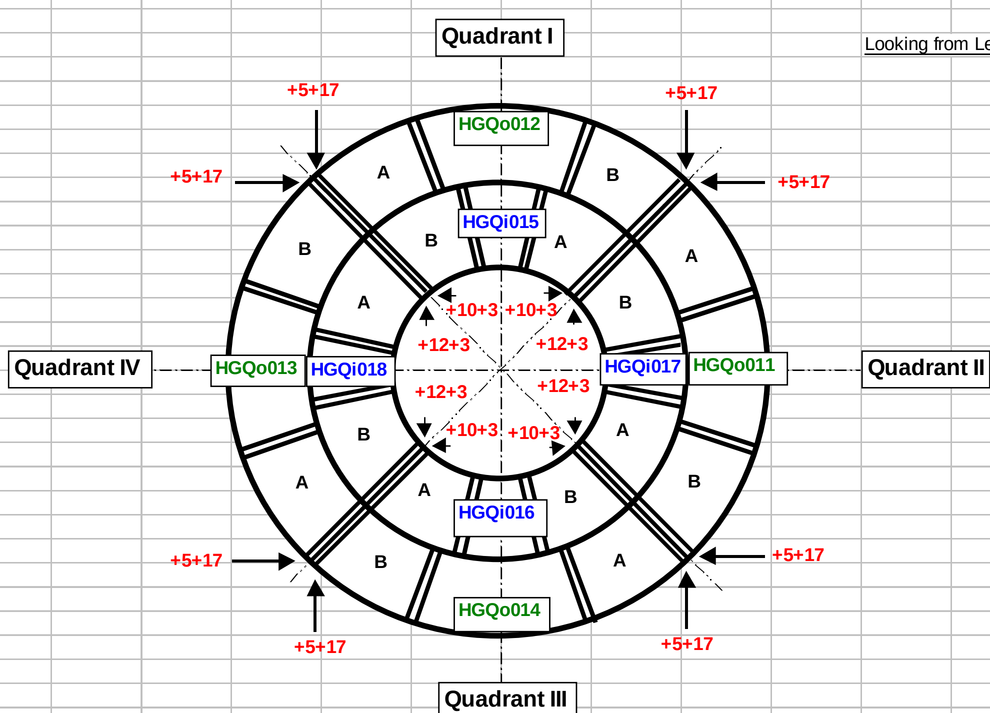


Figure 15. Magnet body cross-section.

Magnet Lead End, Saddle Region I

RADIALY - 7 mil

Looking from Lead to Return End



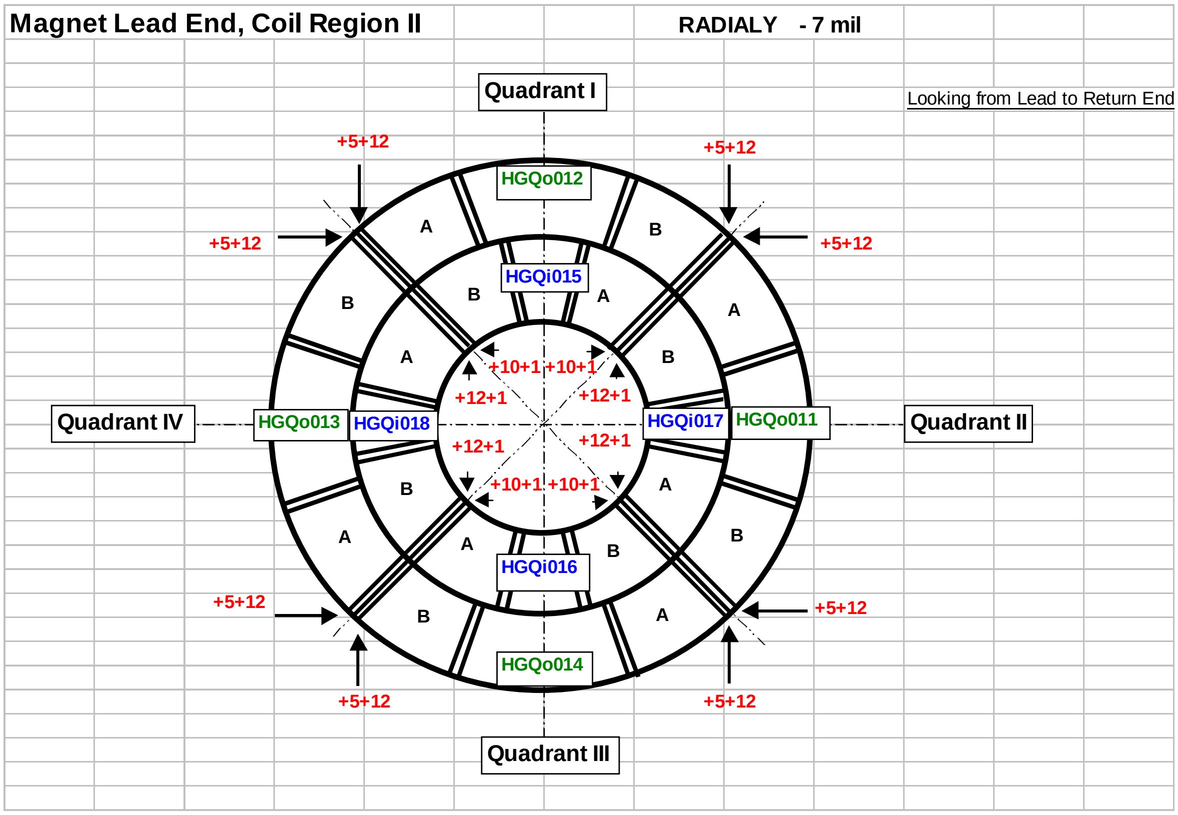


Figure 16. Magnet lead end cross-section, saddle region I.

Figure 17. Magnet lead end cross-section, region II.

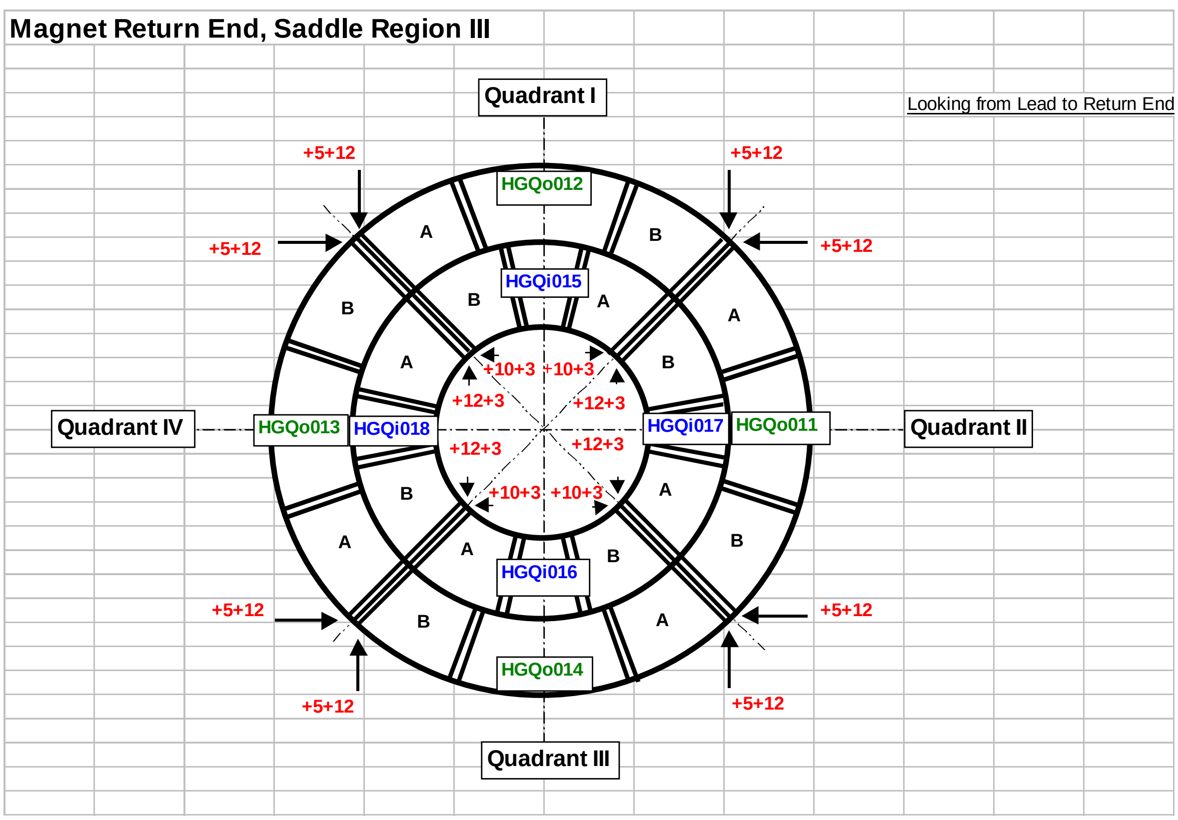


Figure 18. Magnet return end cross-section, saddle region III.

4.3 Quench protection strip heaters.

Quench protection strip heaters were placed in between the inner and the outer layer and also added to the space between the outer layer and the collars (Fig. 19). The strip heater assembly is 75 μm (0.003 in) thick. The heater consists of a 25 μm (0.001 in) stainless steel strip covered on each side by a 25 μm (0.001 in) Kapton "cover sheets". To minimize the preload differences due to the strip outer heater, one of the Kapton cover sheets (the one facing the collars) was removed. In addition, the collar lamination radial surface is known to be 25 μm (0.001 in) large radially(see Appendix, collar inspection). This leaves only 25 μm (0.001 in) extra material radially within the magnet cross section.
Finally, we have175 μm (0.009 in) Kapton insulation between each strip heaters and coils.

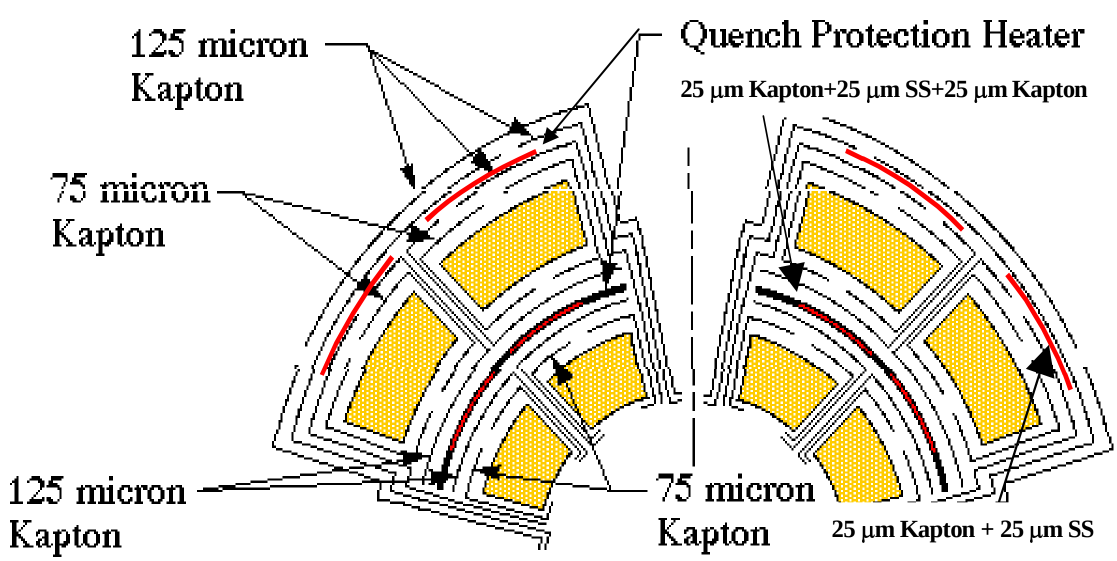


Figure 19. Strip heater location.

At least 125 μm Kapton insulation covered heaters at transition and end areas. The ground wrap was modified specially at Lead and Return Ends to ensure there was no heater-to-collar ground short potential.

4.4 Strain gauges.

Coil size in the different quadrants along the magnet which was calculated according to coil size data and coil location in the magnet is shown in Fig. 20, 21.

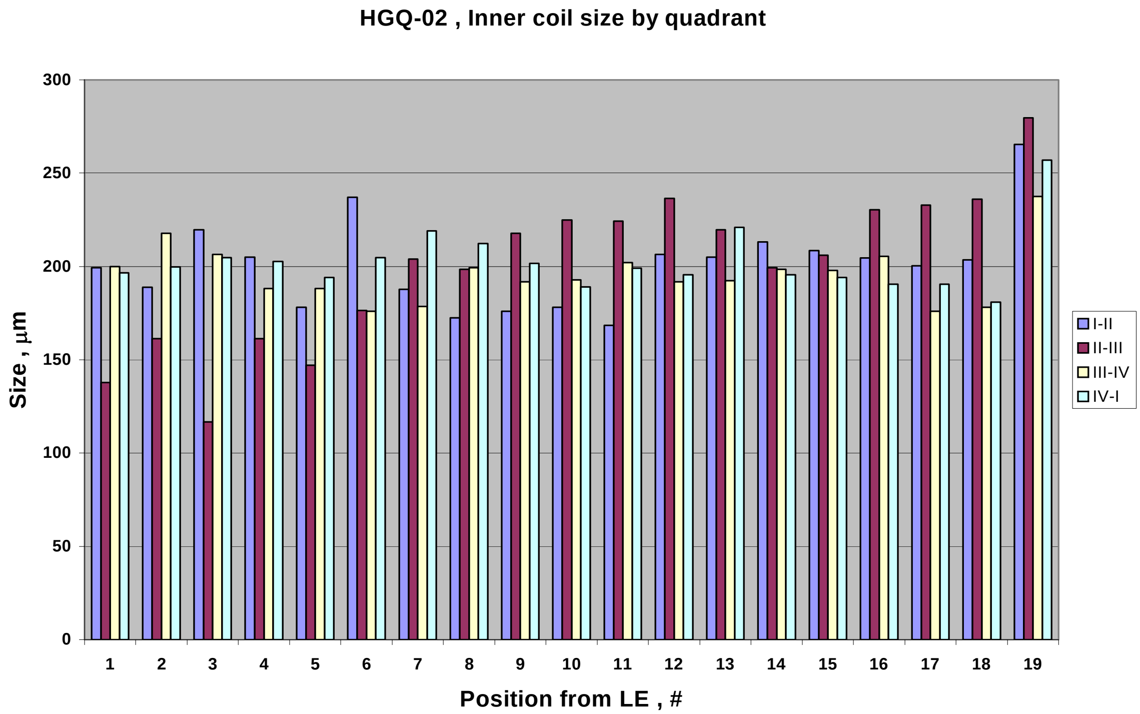


Figure 20. Inner coil size by quadrant along the magnet (with respect to nominal).

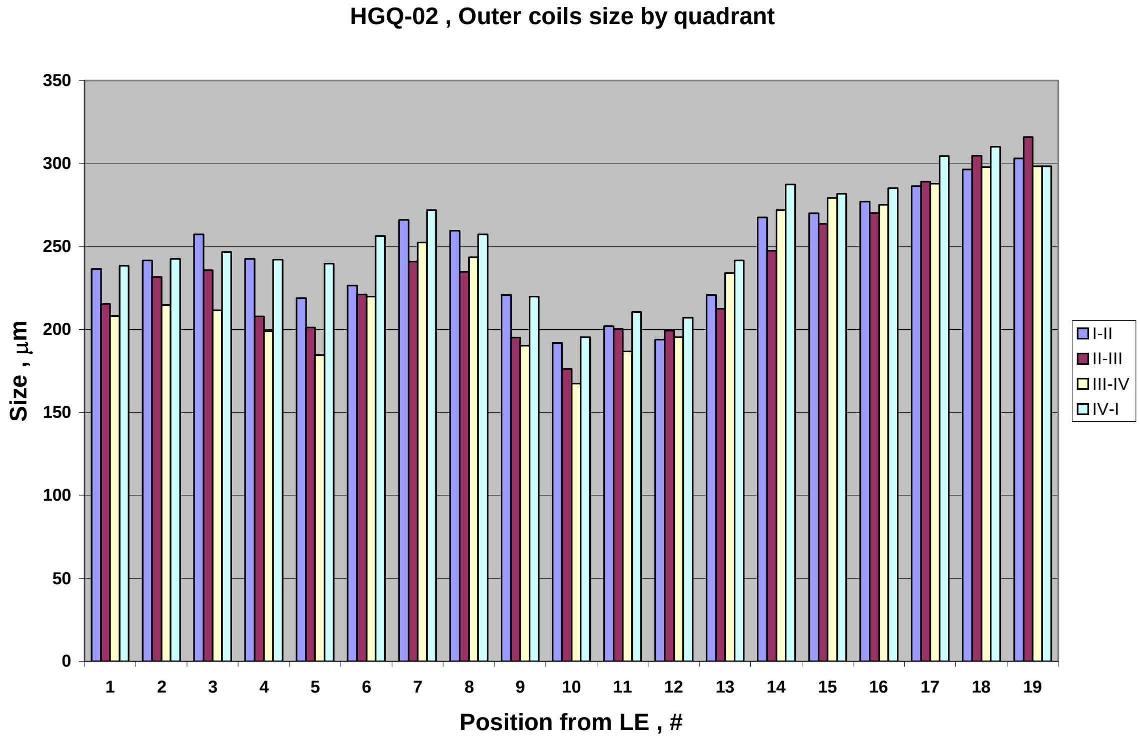
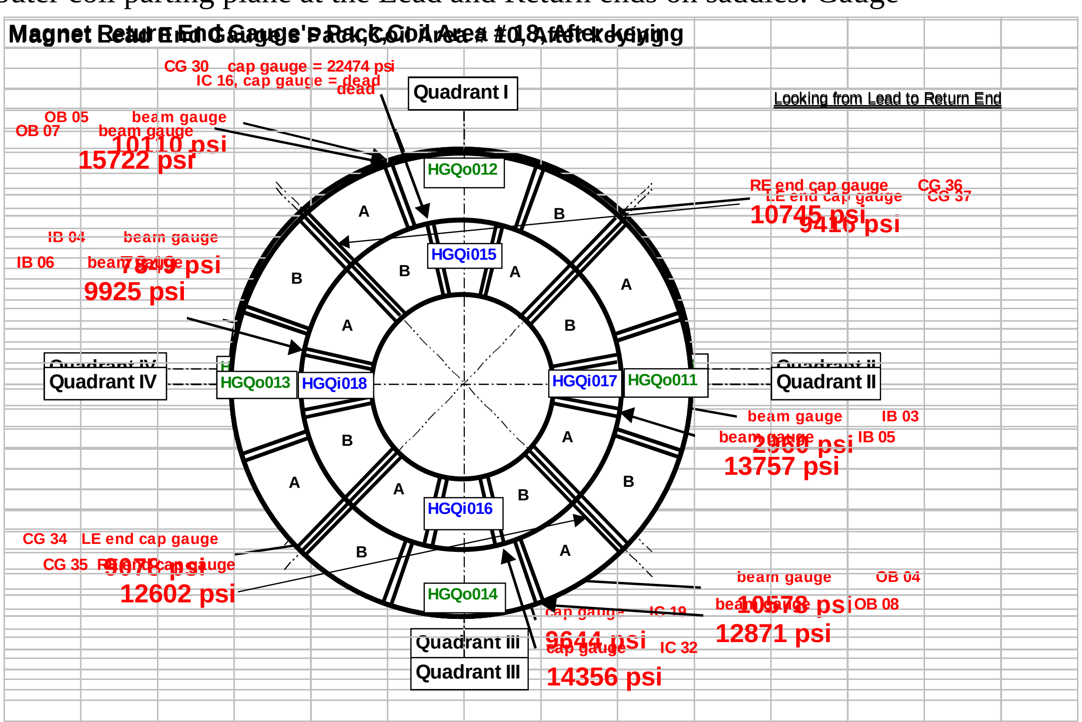


Figure 21. Outer coil size by quadrant along the magnet (with respect to nominal).

Longitudinal positions #10 and #18 in the magnet body were chosen for strain gauge installation. These sections have smallest and biggest azimuthal coil sizes, respectively. Each strain gauge position is instrumented with four beam gauges, four temperature-compensating gauges, and with four capacitance gauges. Additional two capacitance gauges were placed at the outer coil parting plane at the Lead and Return ends on saddles. Gauge



locations are show on Fig. 22, 23.

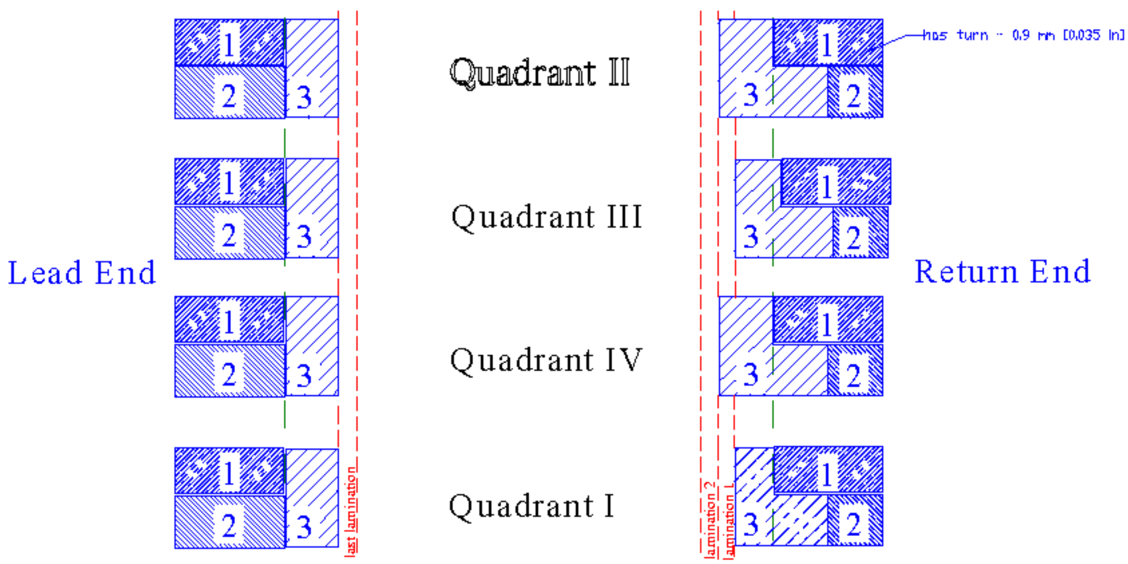
Figure 22. Magnet longitudinal position #10.

Figure 23. Magnet longitudinal position #18.

4.5 Pole extensions.

Pole extensions are 12.7mm (1/2 in) long Ultem pole pieces, which extend longitudinally from the back of the Ultem keys on both the lead and return ends. They fill the pole space of both the inner and outer layers otherwise filled by the collar laminations. The ground wrap can be overlapped in this transition area to prevent cracks, which might create ground shorts.

The location scheme for pole extensions is shown in Fig. 24.



1 – key insert block for outer coil, 2- key insert block for inner coil, 3- pole extension

Figure 24. Pole extension location.

On the lead end of the magnet unmodified (manufactured by design) pole inserts were installed equal to the inner edge of the end, which had the same longitudinal position for each quadrant. On the return end pole inserts were modified to fill spaces between collars and ends completely, because of different coil lengths.

125 μm (.005in) were added to each outer pole face of the pole extensions to compensate for differences in the modulus of Ultem vs. stainless steel and to "partially" compensate for the differential thermal contraction between the

two materials. Two magnet cross-sections with pole insert blocks are show in Fig. 25 and 26.

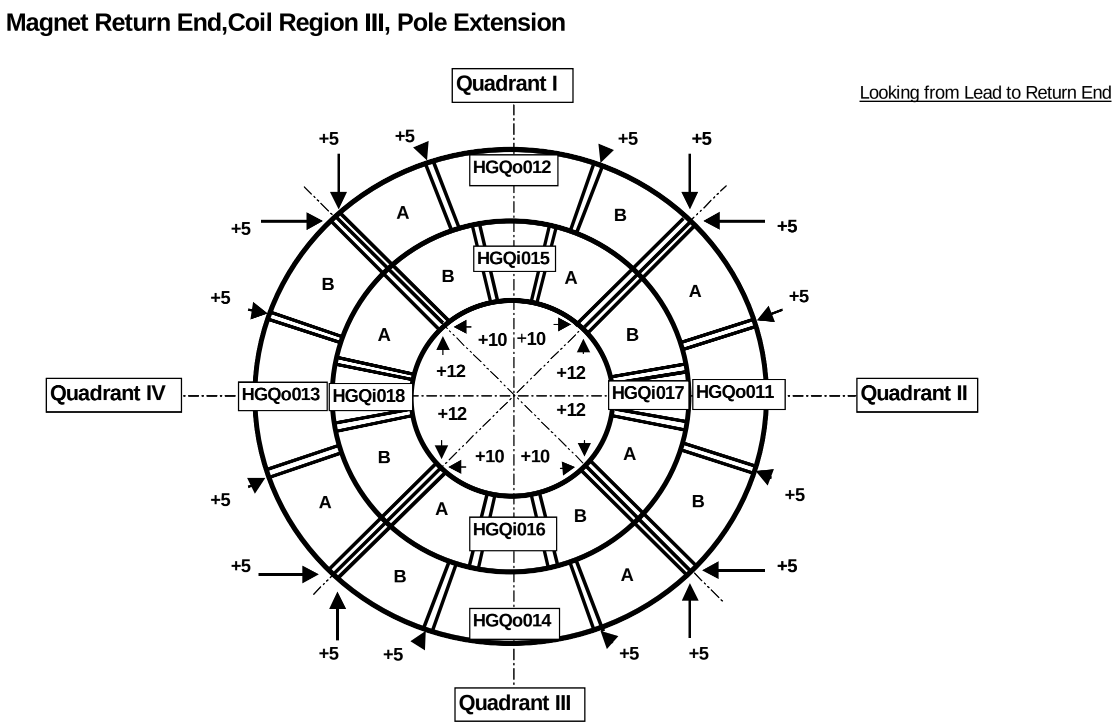


Figure 25. Magnet cross-section with lead end pole extension.

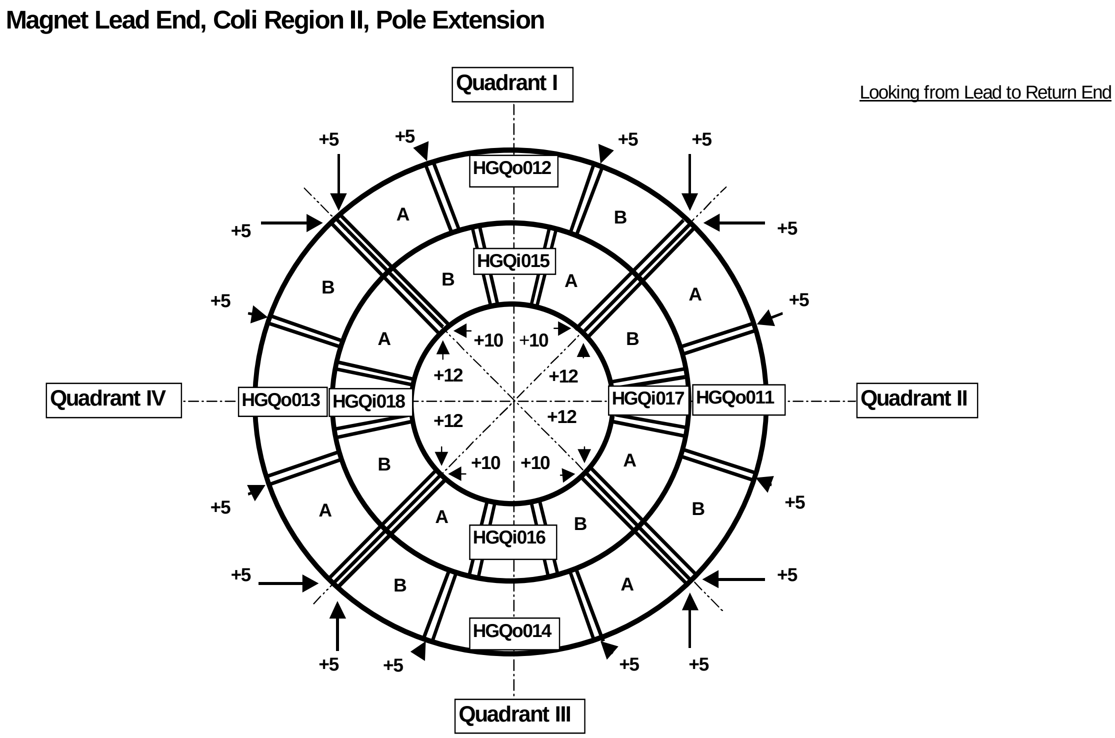


Figure 26. Magnet cross-section with return end pole extension.

4.6 Keying.

After the magnet is assembled, shimmed and collared, the collared assembly is placed into the vertical keying press. The collared assembly is then “massaged”. This consists of pressing the entire length, incrementally, once at 1500 pump psi and again at 3000 pump psi, beginning with the return end of the body section.
The body of the magnet is then keyed. All collars are incrementally compressed to the design position and fixed by inserted keys. The main press release is then released, internal deflections in the collared coil assembly occur, and the coil preload decreases.
The specific keying process for each 3 inch increment is explained below:

A section of the collared coil is compressed by the main hydraulic press to a pressure 6750 pump psi, which allows the keys to be partially inserted by hand. The keys are then inserted further by hydraulic pressure (using a different set of cylinders) at a pump pressure of 3000 psi. While holding 3000 pump psi on the keys, the main press cylinder are then released and pressured again to 6750 pump psi. three more times. This cycling allows the keys to be filly inserted into their respective slots in the collars, while minimizing over compression. It is desirable to avoid over compression as much as possible, because higher assembly pressures increase risks,

particularly of turn-to-turn shorts, to the coils. This process is then repeated, incrementally every three inches, for the length of the magnet body.
The 6750 psi main pump pressure and 3000 psi keying pressure are estimated based on design values, and may vary depending on specific magnet geometry.

After the body is keyed, the return end with "full round" collars is then keyed by a similar process, except that the pressures used and the exact length of the increments are adjusted to compensate for the end geometry.

Distance between main press platens " pushers" is measured during massaging and keying. Measurements are taken with respect to steel "master" which manufactured to the design collared coil size without deflection. These measurements help to understand how much pressure is necessary to begin key insertion, allowing over compression to be minimized.

Q2 had short to ground during keying. It was discovered that the coil on the return end was shorted to the assembly mandrel. The short disappeared after the mandrel was removed.

Strain gauge readings during keying show in Fig. 27.

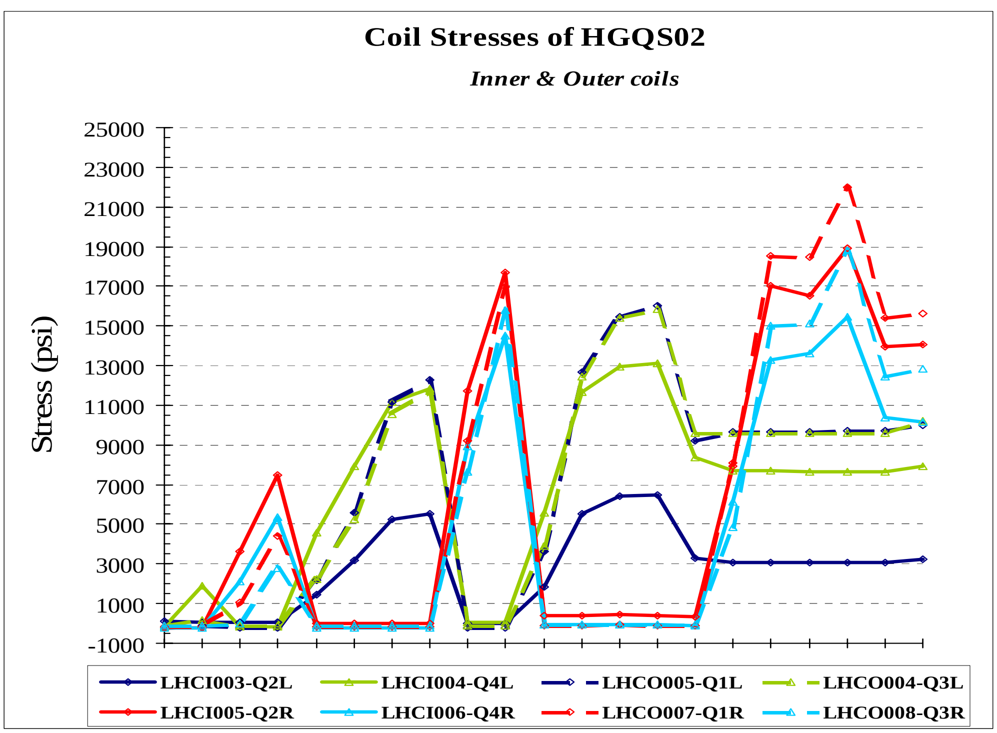


Figure 27. Strain gauges reading during keying.

4.7 Final keyed pressures.

The final pressures after magnet keying are shown in Tab. 9. 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.
The inner beam and capacitor gauges are placed at opposing poles, so in theory, opposing gauges should read close to the same preload. Opposing gauge pairs are:

Inner beam 003 opposes inner capacitor 019 LE
Inner beam 005 opposes inner capacitor 032 RE
Inner beam 004 opposes inner capacitor 016 LE
Inner beam 006 opposes inner capacitor 030 RE

There are no outer coil capacitor gauges.
The “lead end” inner gauges are in the same plane longitudinally as the “lead end” outer gauges, as are the “return end” ones.

Table 9 Final pressures after magnet keying.

Gauge position and number	Maximum stress before “springback”. (Main pump pressure 6750 psi, key pusher pressure 3000 pump psi.)		Final stress after “springback”. All press pressure has been removed. Keys alone support coils.		Stress two weeks later after colleting but before yoking. Collared coil is in free state.	
	psi	MPa	psi	MPa	psi	MPa
Inner beam LE 003	6461	45	3232	22	2960	20
Inner beam LE 004	13096	90	7917	55	7849	54
Inner cap LE 019	14883	103	9589	66	9644	66
Inner cap LE 016	failed		Failed		failed	
Inner beam RE 005	18903	130	14063	97	13757	95

Inner beam RE 006	15462	107	10150	70	9925	68
Inner cap RE 032	19351	133	14103	97	14356	99
Inner cap RE 030	failed		Failed		failed	
Outer beam LE 005	16010	110	10005	69	10110	70
Outer beam LE 004	15834	109	10224	70	10578	73
Outer beam RE 007	21960	151	15622	108	15722	108
Outer beam RE 008	18785	130	12829	88	12871	89
End capacitor gauges						
Outer saddle LE 034					9078	63
Outer saddle LE 037					9416	65
Outer saddle RE 035					12602	87
Outer saddle RE 036					10745	74

4.8 Mechanical measurements.

The OD measurement data for collared coil block show on Fig. 28, 29.

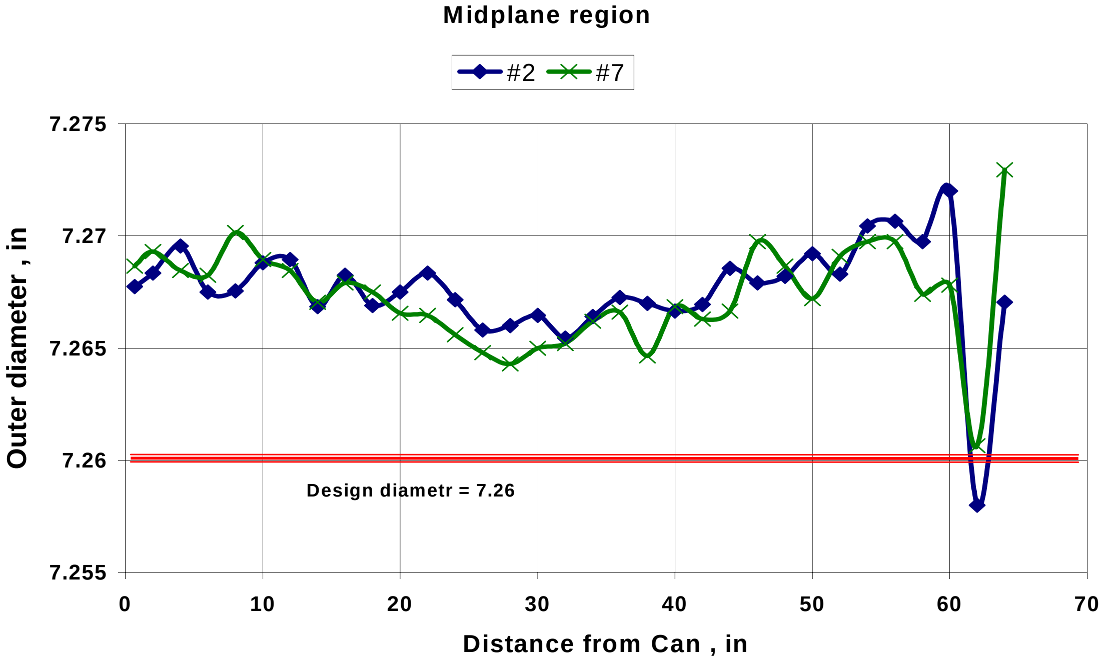


Figure 28. Collared coil deflections at midplane region.

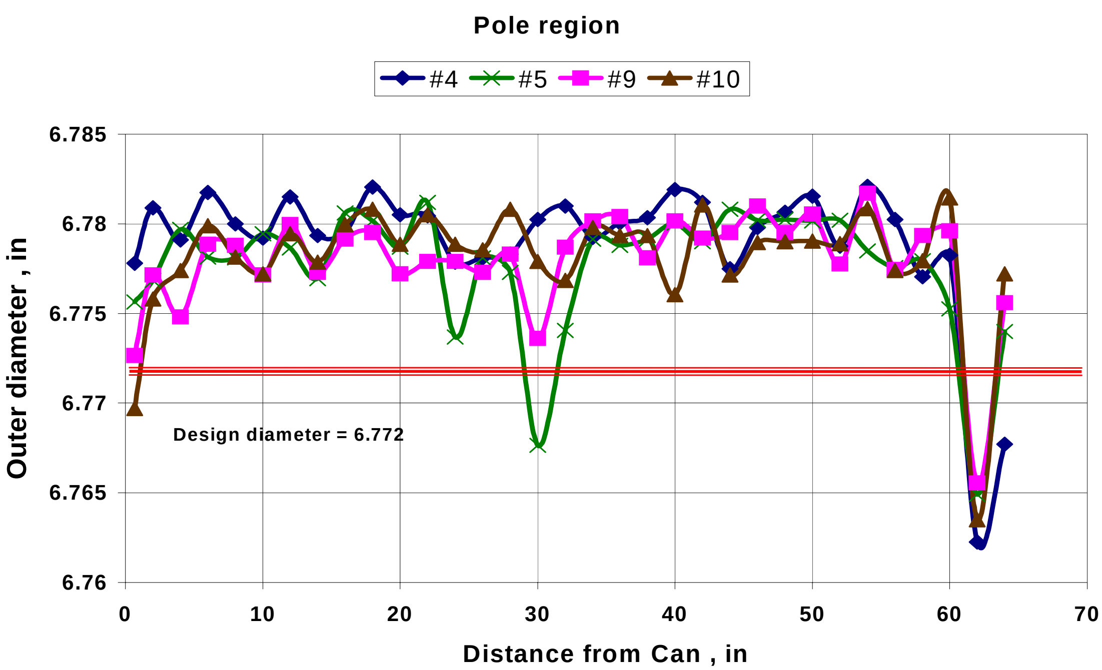


Figure 29. Collared coil deflections at pole region.

4.9 Ramp splice.

The pole turn of each inner/outer coil pair needs to be spliced together. The external splice configuration is used for HGQ-02. Splices are 114 mm long, which is approximately equal to the cable transposition pitch. Areas to be spliced are preformed, or filled with solder before the coil is wound. The tinned sections are then spliced after the magnet straight section is collared and keyed.

4.10 End can.

An illustration of the Lead end region is shown in Fig.30.
The End Can is installed on the lead end of the coil assembly using a longitudinal force of 66660 lbs (at 9750-pump psi). The radial deflection of aluminum ring according pi-tape measurements is ~ 305 μm [0.012 in]. The thickness of radial ground insulation surrounding the outer coil was reduced by 178 μm [0.007 in] from the original design on the radius.

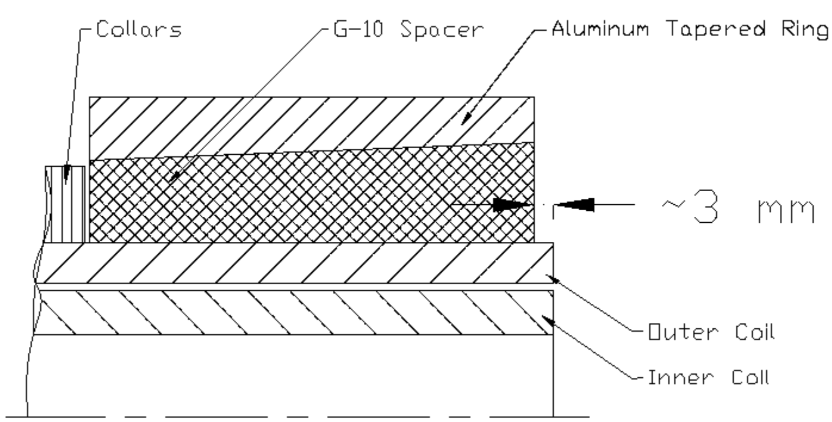


Figure 30. End can region.

5. Cold mass assembly

5.1 Yoking and skinning.

The skin alignment key for magnet HGQ-02 was changed to eliminate the gap between the skin and the alignment key. An additional 4 mm was added to the skin alignment key surface (ref. dwg. MC-344868) based on yoke press measurements of HGQ01 and R&D weld experiments. All lamination packs were fusion welded longitudinally in 7 places (5 welds on outer surface and 2 welds on inner surface).
The magnet was compressed in the weld 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. 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 (see Fig. 31).

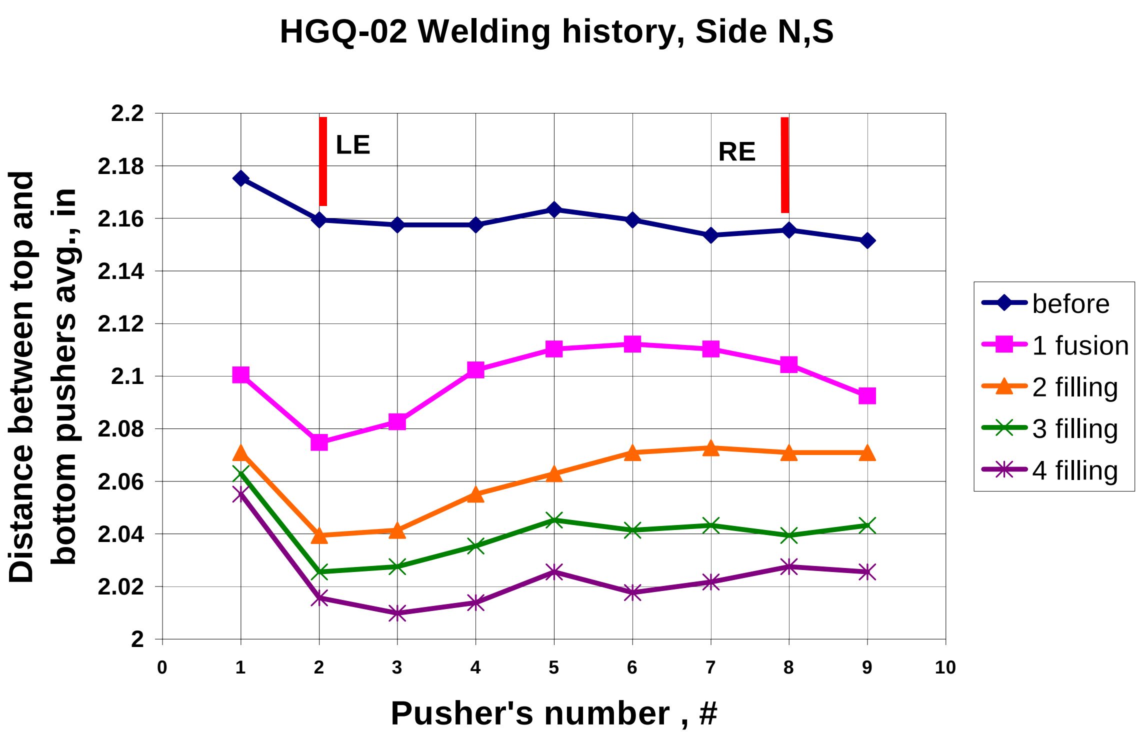


Fig. 31 Distance between top and bottom pushers.

The skin diameter measurements after welding are shown in Fig 32,33.

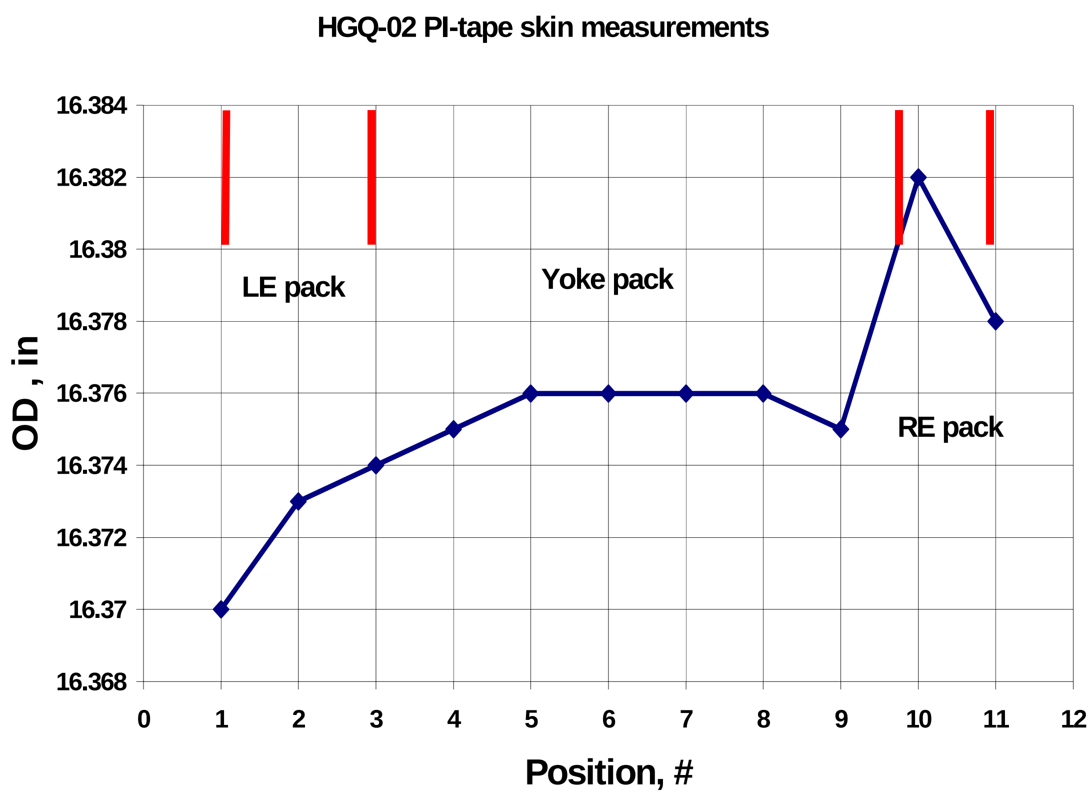


Fig.32 Skin outer diameter according to pi-tape measurements.

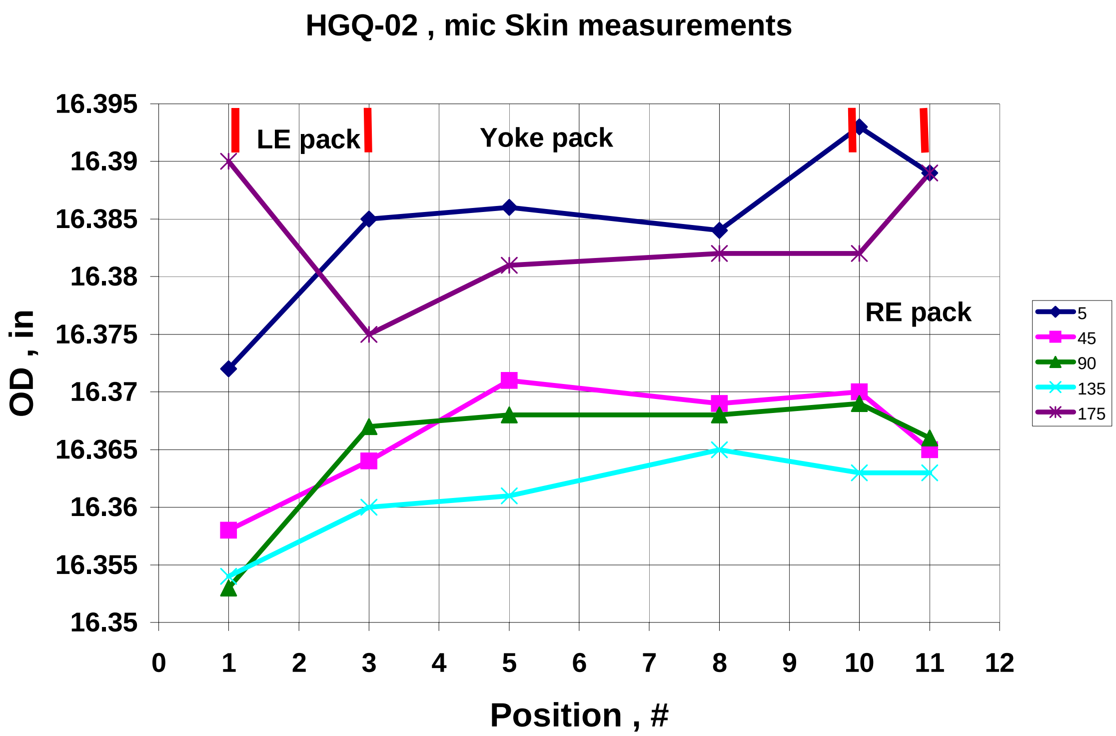


Fig.33 Skin outer diameter according to micrometer measurements.

The skin is still yielded after welding, however the amount of skin travel was reduced and consequently decreased the amount of buckling. The lead end had very slight buckling and has about a 254 µm [10 mil] gap between the collet and yoke. The return end had very noticeable buckling and a 50 µm [2 mil] gap between the collar and yoke assemblies.

5.2 Bullet installation

The history of bullet loading and plots for bullet force as a function of travel show below.

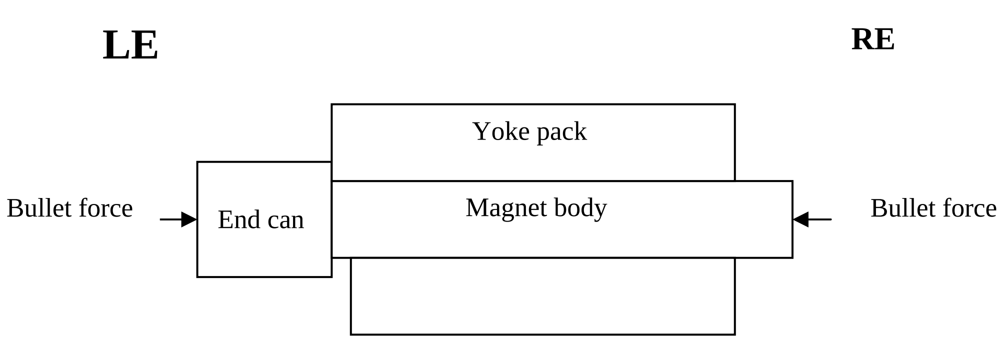


Fig. 34 Yoke – End can interface.

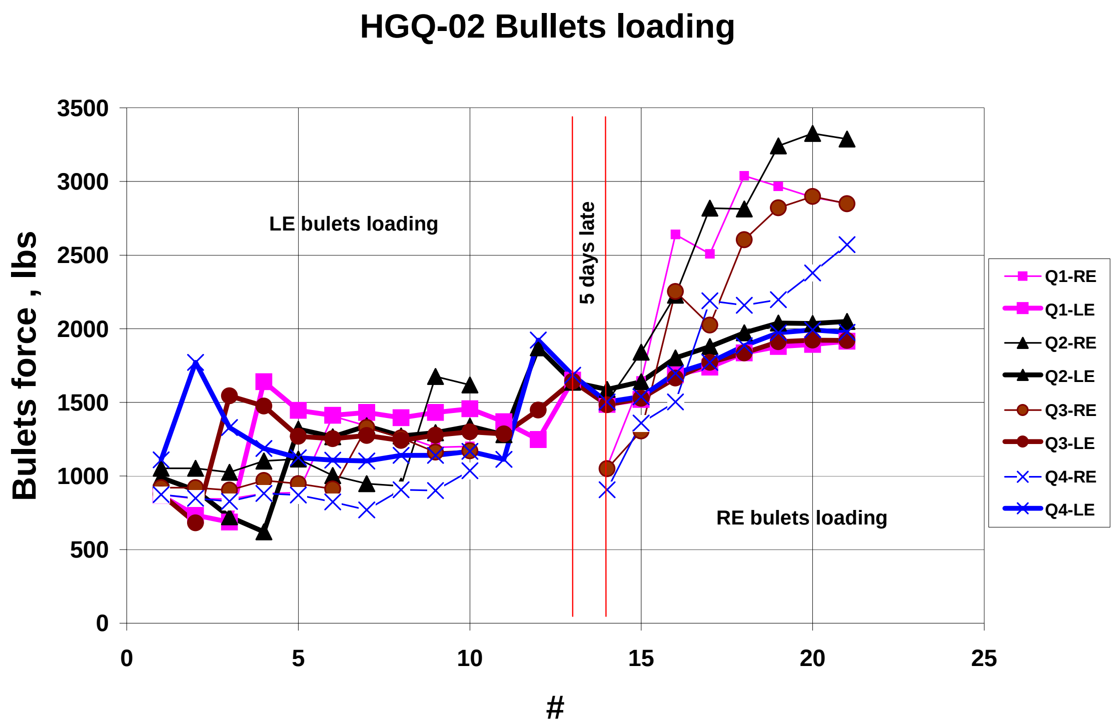


Fig. 35 Bullets load history.

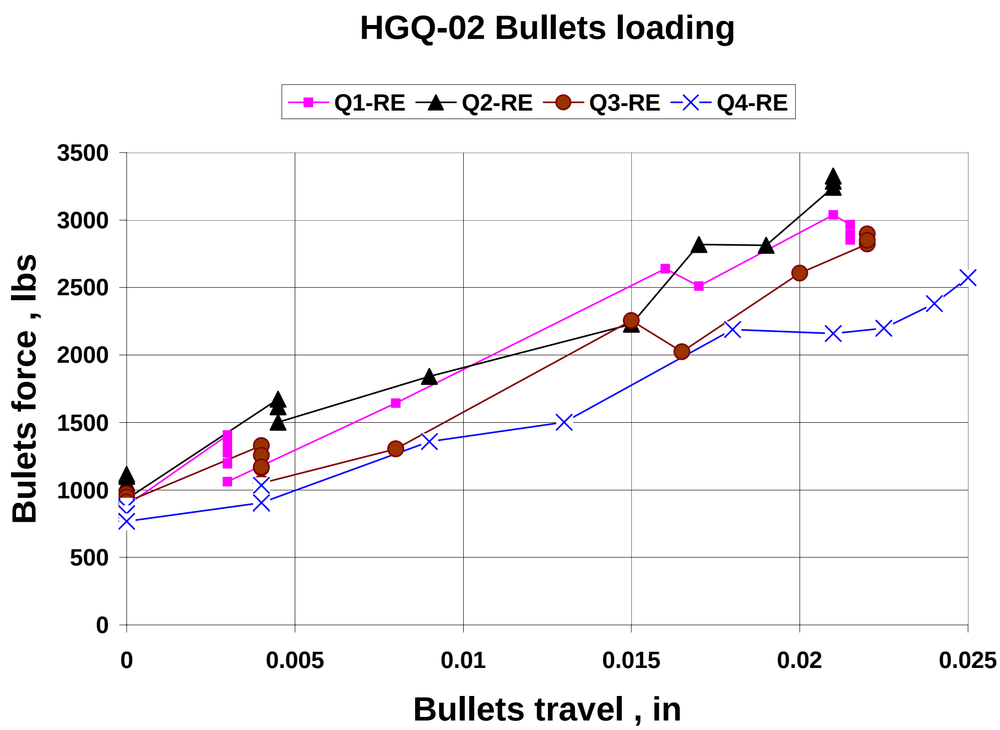


Fig. 36 Return end bullet travel vs. applied force.

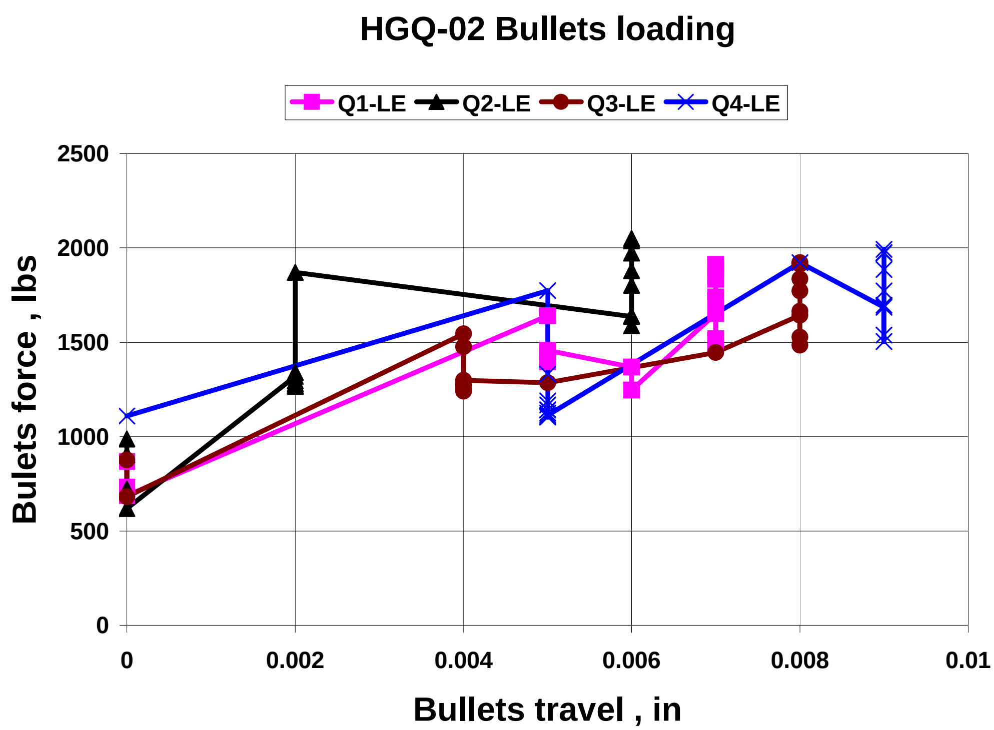


Fig. 37 Lead end bullet travel vs. applied force.

6. **Magnet production test**

6.1Hi potting

Three changes were implemented on HGQ02 to prevent hi pot failure occurred during the final electrical inspection.

- The space between the last yoke lamination and the end plate was increased to 9mm .
- The hole in the end plate has been chamfered on the inside surface.
- Kapton sheets (.005 inches) were added to the inside surface of the end plate and the outside surface of the yoke laminations.

Magnet HGQ02 was hi potted coil to ground, heater to ground and heater to coil at 1500 volts instead of the standard 5000 volts for coil to ground and 3000 volts for heater to ground and heater to coil.
Leakage is required to be less than 0.5 μA at 1500 V.

After collet installation but before yoke
4-16-98 after nitrogen purge
(RE heaters potted)

		To ground	To coils
Heater pos.	Layer	leakage @ 1500 V	
Q1-Q2	inner	.42μA	.42μA
Q2-Q3	inner	.10μA	.28μA
Q3-Q4	inner	.02μA	.02μA
Q4-Q1	inner	.02μA	.02μA
Q1-Q2	outer	.06μA	.08μA
Q2-Q3	outer	.10μA	.28μA
Q3-Q4	outer	.02μA	.02μA
Q4-Q1	outer	.02μA	.01μA

Coil - Ground = .04μA (4/15)

After yoke and skin but before welding and plate
4-23-98 after nitrogen purge
(RE and LE heaters potted)

		To ground	To coils
Heater pos.	Layer	leakage @ 1500 V	
Q1-Q2	inner	.20μA	.02μA
Q2-Q3	inner	.08μA	.10μA
Q3-Q4	inner	.02μA	.02μA
Q4-Q1	inner	.02μA	.02μA
Q1-Q2	outer	.02μA	.02μA
Q2-Q3	outer	.20μA	.5μA@700V
Q3-Q4	outer	.02μA	.02μA
Q4-Q1	outer	.02μA	.02μA

Coil - Ground = .04μA

After collet installation but before yoke
4-16-98 after nitrogen purge
(RE heaters potted)

		To ground	To coils
Heater pos.	Layer	leakage @ 1500 V	
Q1-Q2	inner		
Q2-Q3	inner	.5μA@600V	.5μA@750V
Q3-Q4	inner		
Q4-Q1	inner	.5μA@130V	.5μA@400V
Q1-Q2	outer	.44μA	.20μA
Q2-Q3	outer		
Q3-Q4	outer	.03μA	.03μA
Q4-Q1	outer		

Coil - Ground = .12μA

After yoke and skin but before welding and plate
4-23-98 after nitrogen purge
(RE and LE heaters potted)

		To ground	To coils
Heater pos.	Layer	leakage @ 1500 V	
Q1-Q2	inner	.12μA	.08μA
Q2-Q3	inner	.44μA	.42μA
Q3-Q4	inner	.16μA	.18μA
Q4-Q1	inner	.5μA@800V	.5μA@1200V
Q1-Q2	outer	.11μA	.10μA
Q2-Q3	outer	.5μA@1000V	.5μA@1200V
Q3-Q4	outer	.03μA	.03μA
Q4-Q1	outer	.18μA	.18μA

Coil - Ground = .2μA

6.2 Magnet electrical data

Table 38. Electrical parameters (final test data).

	Resistance , ohm	Ls , mH	Q
Q1 - inner	**0.0815**	**0.16510**	**1.03**
Q1 - outer	**0.1122**	**0.28805**	**1.28**
Q2 - inner	**0.0818**	**0.16538**	**0.93**
Q2 - outer	**0.1122**	**0.28850**	**1.27**
Q3 - inner	**0.0819**	**0.16519**	**1.03**
Q3 - outer	**0.1119**	**0.28862**	**1.33**
Q4 - inner	**0.0830**	**0.16721**	**1.03**
Q4 - outer	**0.1128**	**0.28879**	**1.36**

Q1 – Quadrant total	**0.1943**	**0.72239**	**2.70**
Q2 – Quadrant total	**0.1935**	**0.72012**	**2.61**
Q3 – Quadrant total	**0.1942**	**0.72336**	**2.71**
Q4 – Quadrant total	**0.1941**	**0.72110**	**2.64**
Magnet total	**0.7777**	**4.385**	**3.09**

Table 39. Heaters resistance.

Heater	Resistance , ohm	Heater	Resistance , ohm
Q1/2 - inner		**Q1/2 – outer**	**7.263**
Q2/3 - inner	**7.307**	**Q2/3 – outer**	
Q3/4 - inner		**Q3/4 – outer**	**7.288**
Q4/1 - inner	**7.282**	**Q4/1 – outer**	

6.3 Warm magnetic measurements

The warm magnetic measurement data are posted on the WEB at **http://tsmtf.fnal.gov/~dimarco/HGQS_test_data.html**. In order to look at the plots you will have to run netscape from a x window connected to mdtf20 (or other unix machine).

Below, I also include some tabular information from the three center most z positions -0.25m, 0.0, +0.25m
-Joe
-After keying:

---

zpos -0.250 cur 10.018 (A)
N rot 47 time 1234.48 (s)
TF 2.80706e-04 TFerr 1.21316e-08 (Tesla/Amp at 1.70cm)
Field 2.81214e-03 (Tesla at 1.70cm)
dx 0.07 dy -0.00 (cm)

---

avg s.d.m (in units at 1.70cm)

---

b1	-0.00176	0.01819
b2	10000.00000	0.06246
b3	-0.86380	0.00504
b4	0.35523	0.00322
b5	-0.21585	0.00377
b6	-2.27175	0.00876
b7	0.02218	0.00564
b8	-0.05028	0.00868
b9	-0.07076	0.01200
b10	-0.15464	0.01675
b11	0.13278	0.02857
b12	0.09101	0.02730

a1	-0.00159	0.01790
a2	0.00000	0.08833
a3	-0.78428	0.00504
a4	0.58833	0.00322
a5	-0.04292	0.00377
a6	0.15879	0.00876
a7	0.02961	0.00564
a8	-0.11939	0.00868
a9	-0.21472	0.01198
a10	-0.16530	0.01675
a11	-0.08027	0.02858
a12	0.28230	0.02731

---

zpos 0.000 cur 10.007 (A)
N rot 47 time 247.20 (s)
TF 2.80426e-04 TFerr 1.41514e-08 (Tesla/Amp at 1.70cm)
Field 2.80608e-03 (Tesla at 1.70cm)
dx 0.09 dy -0.00 (cm)

---

	avg	s.d.m (in units at 1.70cm)
b1	-0.00249	0.02377
b2	10000.00000	0.07197
b3	-0.83185	0.00442
b4	0.08773	0.00249
b5	-0.20408	0.00287
b6	-2.03773	0.00588
b7	-0.01366	0.00349
b8	0.01423	0.00576
b9	-0.08816	0.00925
b10	-0.31776	0.01635
b11	-0.12157	0.02078

b12	-0.09235	0.02089

a1	-0.00202	0.02519
a2	0.00000	0.10177
a3	-0.74632	0.00442
a4	-0.09804	0.00250
a5	-0.04179	0.00286
a6	-0.08740	0.00589
a7	-0.01191	0.00348
a8	-0.03126	0.00574
a9	0.03671	0.00930
a10	0.18211	0.01604
a11	0.14471	0.02077
a12	-0.13898	0.02033

---

zpos 0.250 cur 10.022 (A)
N rot 48 time 1900.05 (s)
TF 2.80561e-04 TFerr 1.52515e-08 (Tesla/Amp at 1.70cm)
Field 2.81192e-03 (Tesla at 1.70cm)
dx 0.09 dy 0.00 (cm)

---

	avg	s.d.m (in units at 1.70cm)
b1	-0.00206	0.02806
b2	10000.00000	0.07801
b3	-0.68941	0.00770
b4	0.04534	0.00579
b5	-0.19560	0.00645
b6	-2.15121	0.01309
b7	-0.05821	0.00707
b8	-0.08404	0.01058
b9	-0.00576	0.01621
b10	-0.20953	0.02730
b11	0.32148	0.04499

b12	-0.08988	0.04760

a1	-0.00211	0.02761
a2	0.00000	0.11033
a3	-0.72725	0.00770
a4	-0.13602	0.00579
a5	-0.10181	0.00646
a6	-0.03232	0.01311
a7	0.00385	0.00702
a8	-0.07002	0.01055
a9	-0.09607	0.01616
a10	-0.10451	0.02734
a11	-0.15993	0.04467
a12	-0.36225	0.04745

- **After yoking:**

Below are data from the three center-most z-positions for the yoked magnetic measurements in IB3. Note that transfer function has to be divided by (0.017m *.001kA) to get to T/m/kA.

- Joe

_

zpos -0.250 cur 9.014 (A)
N rot 48 time 623.08 (s)
TF 3.05629e-04 TFerr 1.32805e-08 (Tesla/Amp at 1.70cm)
Field 2.75506e-03 (Tesla at 1.70cm)
dx -0.04 dy -0.01 (cm)

_

	avg	s.d.m (in units at 1.70cm)
b0	0.00065	0.03015
b1	10000.00000	0.06242
b2	0.74778	0.00365
b3	-0.33159	0.00196
b4	-0.02206	0.00270
b5	-2.12861	0.00648
b6	0.04642	0.00353
b7	0.07276	0.00532

b8	-0.01907	0.00737
b9	-0.18047	0.01274
b10	0.10056	0.02268
b11	0.04014	0.03227

a0	-0.00011	0.03006
a1	0.00000	0.08827
a2	-0.65957	0.00364
a3	-0.70210	0.00197
a4	0.15351	0.00273
a5	0.13503	0.00647
a6	0.01506	0.00353
a7	-0.06241	0.00532
a8	0.12727	0.00711
a9	0.01327	0.01314
a10	-0.06675	0.02278
a11	0.01466	0.03231

---

zpos 0.000 cur 9.017 (A)
N rot 50 time 1073.98 (s)
TF 3.06217e-04 TFerr 9.86335e-09 (Tesla/Amp at 1.70cm)
Field 2.76114e-03 (Tesla at 1.70cm)
dx -0.06 dy -0.03 (cm)

---

avg s.d.m (in units at 1.70cm)

_

b0	0.00160	0.02067
b1	10000.00000	0.04501
b2	0.72429	0.00446
b3	-0.09414	0.00258
b4	-0.14154	0.00314
b5	-1.75105	0.00942
b6	0.07350	0.00377
b7	-0.07452	0.00730
b8	0.09546	0.00814
b9	-0.34094	0.01538

b10	0.23953	0.02897
b11	0.09160	0.03872

a0	0.00039	0.02067
a1	0.00000	0.06365
a2	-0.59542	0.00446
a3	0.02118	0.00260
a4	0.13490	0.00327
a5	-0.00127	0.00941
a6	0.04336	0.00382
a7	-0.09881	0.00699
a8	0.12287	0.00835
a9	0.08423	0.01555
a10	-0.02970	0.02951
a11	0.02761	0.03776

---

zpos 0.250 cur 9.019 (A)
N rot 49 time 1542.34 (s)
TF 3.05991e-04 TFerr 1.72253e-08 (Tesla/Amp at 1.70cm)
Field 2.75971e-03 (Tesla at 1.70cm)
dx -0.09 dy -0.03 (cm)

---

avg s.d.m (in units at 1.70cm)

_

b0	0.00260	0.06601
b1	10000.00000	0.08012
b2	0.64862	0.00603
b3	-0.08315	0.00371
b4	-0.12316	0.00464
b5	-1.73480	0.01103
b6	0.01987	0.00594
b7	0.10589	0.00887
b8	-0.09825	0.01295
b9	-0.12619	0.02046

b10	0.07815	0.02999
b11	-0.14088	0.03659

a0	0.00005	0.06906
a1	0.00000	0.11330
a2	-0.43976	0.00603
a3	-0.03448	0.00371
a4	0.11573	0.00449
a5	0.13238	0.01106
a6	0.00734	0.00593
a7	0.06847	0.00888
a8	-0.09901	0.01328
a9	0.08078	0.02048
a10	-0.04268	0.03074
a11	-0.09850	0.03767

7. Appendix

7.1 Cable certification

CABLE No. LHC-3-I-00596

CABLE LOG SHEET **The inner cable**

real is 596.

LBNL-SUPERCON-AFRD
SUPERCONDUCTING MAGNET MATERIALS
BLD 52
- STRAND INFORMATION -

MANUFACTURER : IGC
BILLET # : B20360
SPOOL # : 1,2…,19
COMPOSITION : NbTi
STRAND Dia.. NOMINAL : .808 mm INSP. DIA..: .810 mm avg.
Cu/SC RATIO NOMINAL : INSP. RATIO : na
FILAMENT TWIST/LENGTH : 1/12.7 mm DIRECTION : LEFT
SHARP BEND TEST :
LENGTH PER SPOOL : 950 m

NOTES:
-CABLING SPECIFICATION –

TYPE or SPEC.: LHC-HGQ-INNER Type#3
No. of STRANDS : 38
PITCH DIRECTION : RIGHT PITCH LENGTH : 114 mm
PLANETARY RATIO : +.57:1
ROLLER ID #: P23 & P24 WIDTH : 15.254 mm ANGLE : 1.10deg.
MANDREL ID #: 21 WIDTH : 15.15 mm THICKNESS : .60 mm
LUBRICATION : 4BR 100% drip.
STRAND TENTION : 2.1 kg.+/-.1 kg TURKS HEAD LOAD “SGM”: -40.0 kgm.
Nom. THICKNESS : 1.457 mm+/-.006 mm
Nom. WIDTH : 15.400 mm+/-.025 mm
Nom. ANGLE : .99 deg. +/-0.1 deg.

- FINISHED CABLE -

FINISHED LENGTH : 882 m
Avg. THICKNESS : **1.4559 mm**
Avg. WIDTH : **15.3975 mm**
Avg. ANGLE : **1.048 deg.**

RESIDUAL TWIST/Mtr.: 25 deg. Good direction. OK “Straightening tightens the cable”
ETCH for FILAMENT DAMAGE : OK

NOTES : Strands are "high-low" on major edge of cable and only on the top side as mfg.

Run #597 will test short length for pitch length.

4 m sample Arupe Ghosh
4 m sample LBNL archive

CABLE No. LHC-4-F-00599

The outer cable

CABLE LOG SHEET

real is 599.

LBNL-SUPERCON-AFRD
SUPERCONDUCTING MAGNET MATERIALS
BLD 52

- STRAND INFORMATION -

MANUFACTURER : Furukawa
BILLET # :
SPOOL # : 2-1-11001-A-01 & 2-F-11001-F-01
COMPOSITION : NbTi
STRAND Dia.. NOMINAL : .648 mm INSP. DIA..: .650 mm avg.
Cu/SC RATIO NOMINAL : 1.8:1 INSP. RATIO :
FILAMENT TWIST/LENGTH : 12.7 mm DIRECTION : RIGHT
SHARP BEND TEST : OK 3/3
LENGTH PER SPOOL : 750 m

NOTES: This run continued from # 598 Samples A,B…F + F2

-CABLING SPECIFICATION –

TYPE or SPEC.: LHC-HGQ OUTER
No. of STRANDS : 46
PITCH DIRECTION : LEFT PITCH LENGTH : 101.6 mm
PLANETARY RATIO : +.57:1
ROLLER ID #: P-25 & P26 WIDTH : 15.323 mm ANGLE : .69 deg.
MANDREL ID #: 21 WIDTH : 14.95 mm THICKNESS : .49 mm angled tip.
LUBRICATION : 4BR with 5% TUF OIL
STRAND TENTION : 2 +/-.1 Kg TURKS HEAD LOAD "SGM": -43.0 Kgm.
Nom. THICKNESS : 1.146 mm+/-.006 mm
Nom. WIDTH : 15.400 mm+/-.025 mm
Nom. ANGLE : . 68 deg. +/-0.1 deg.

- FINISHED CABLE -

FINISHED LENGTH : 735 m
Avg. THICKNESS : **1.1456 mm**
Avg. WIDTH : **15.3951 mm**

Avg. ANGLE : **.702 deg**.

RESIDUAL TWIST/Mtr.:
ETCH for FILAMENT DAMAGE :

NOTES : 4 m sample Arupe Ghosh
4 m sample LBNL archive