6/30/08
TD-08-022

LARP TQC02a Magnet Test Summary

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Content:

1. Introduction

TQC02a magnet is a continuation of the TQC short model series assembled at Fermilab. All coils of this quadrupole were new, never tested previously, although 2 coils (17 and 19) already went through the mechanical assembly procedure: during the original collaring process two coils - 16 and 18 - were presumed to be subjected to excessive strain (~200Mpa) and damaged when a mid-plane shim slipped. The structure was therefore disassembled, and rebuilt with two new coils, 24 and 27.

The total length of cable in the magnet is ~216 m. All coils are made of 27-strand Rutherford cable with 1-mm Nb_3Sn RRP (54/61) strands. However, the strands for these cables came from several different billets: coils 16-19 from 940R, coils 24-25 from 946R, and coils 26-27 from 947R. All coils were wound and cured at Fermilab. Coils 17, 19, 24, and 25 were reacted and impregnated at LBNL. Coils 26 and 27 were reacted and impregnated in the new long oven at Fermilab. Inspection of Coil 25 showed “Tin leaks” on cable edges where electrical probes were made to measure turn-to-turn resistance. Reacted cable witness samples from coil 26 showed some burst strands along the cable edges, and the coil impregnation was slightly incomplete at one edge. Thus, coils 24 and 27 were selected for use in this magnet. Bronze pole pieces for all coils were used, with the outer pole pieces glued in place for 24 and 27, and not glued in 17 and 19. Tests of cable short samples predict a quench current (SSL) of 13.5 kA at 4.5 K, and 14.8 kA at 1.9 K.

The magnet was delivered to the Fermilab magnet test facility on January 23rd and it was electrically checked by February 1st. The VMTF dewar was filled with liquid helium on February 3rd. The magnet test was started on February 6th and was completed on February 24th.

The Voltage Spike Detection System (VSDS) was used for detection of small magnetic flux changes in the magnet. Results of the TQC02a spike data analyses, as well as of the magnet mechanical analyses, will be presented in a separate note.

2. Instrumentation

The magnet was equipped with two strip heaters on each coil, located on the outer surface of the outer layer. Heaters were made of stainless steel with copper plating in coils 17, 19 and 24, and without the copper plating in coil 27. Therefore resistance of heater in coil 27 was almost twice as large as resistance of heaters in other coils. To have similar resistance of the heater firing circuits, the heaters in coils 17 and 19, as well as in coils 24 and 27, were connected in series according to the scheme shown in Fig.1. ***A*** and ***D*** pairs of the heater terminals (see Fig.1), as well as ***B*** and ***C*** pairs, were connected in parallel to the different heater firing units (HFU). Both HFU were set in protection mode with the heater supply voltage at 300 V and with 0 ms delay. The dump delay was set to 1 ms. Only one spot heater was mounted, at the return end pole turn on coil 19.

Voltage tap system covers the inner and outer coil layers, pole turn, multi-turn and splice sections (see Fig.2). The KEK/HGQ 3-section quench antenna was used during the test to help locate the quench origins.

63 strain gauges were installed at different places (poles, control spacers, skin and bolts) for monitoring mechanical strain and calculating coil stresses during the magnet construction and testing.

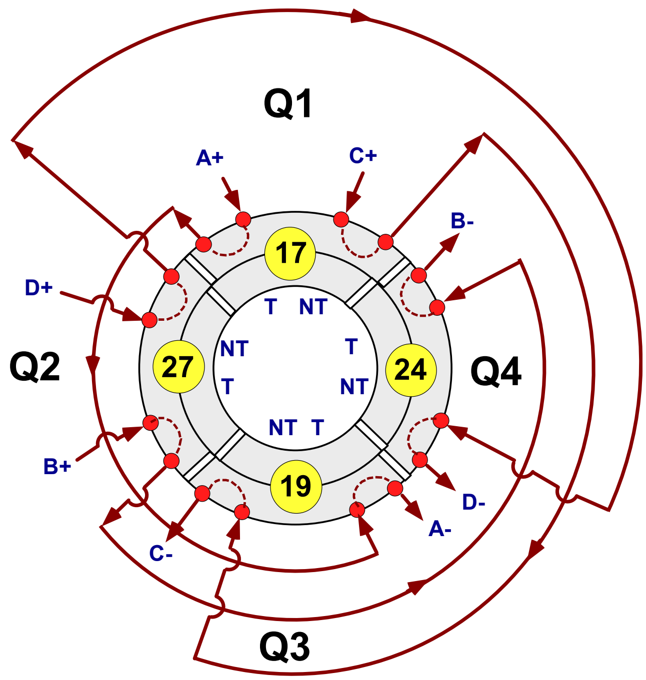

Figure 1. TQC02a strip heater wiring layout (looking from the lead end to the return end).

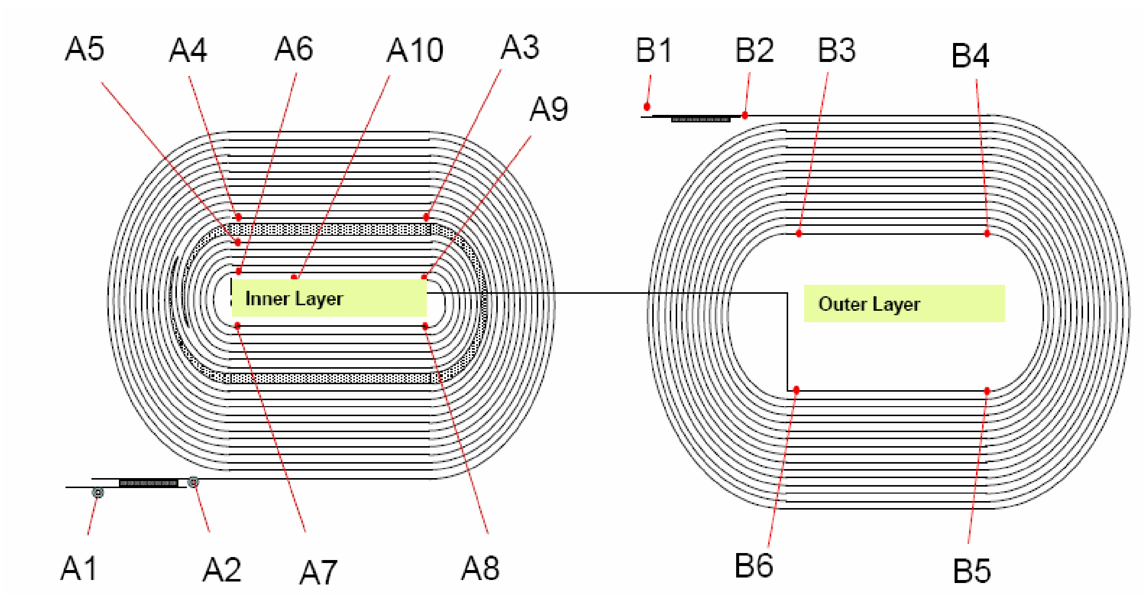

Figure 2. TQC02a voltage tap locations for the inner (left) and outer (right) layers.

Initial signal checking at 4.5 K showed that during the cool down we lost two strain gauges: one on the bullets (*Bu56Aq4*) and one on the control spacer (*Cs24-7*) of the magnet. One voltage tap on the inner layer of coil 24 (***A9*** in Fig.2) was found open and later (after quench 14) configurable voltage tap (CVT) segments were reassigned at the CVT patch panel to join two adjacent segments around the open voltage tap into the one segment.

The quench detection threshold for the half-coil signal was set to 750 mV (signals from the coils 17 and 19 formed the 1st half-coil signal, and signals from the coils 24 and 27 formed the 2nd half-coil signal).

3. Quench History

The magnet test program started at 4.5 K with quench training at the 20 A/s ramp rate. In the beginning, coil 24 exhibited some training in the current range of 8-9 kA and then coil 27 started quenching at ~9.2 kA without any training. After 5 consecutive quenches in coil 27 at the same current, we started the 4.5 K ramp rate study. All 4.5 K quenches are shown in Fig.3. Note that coil 24 did not quench again at 4.5 K after quench #19. At 4.5K coil 17 developed quenches only at high ramp rate and coil 19 did not quench..

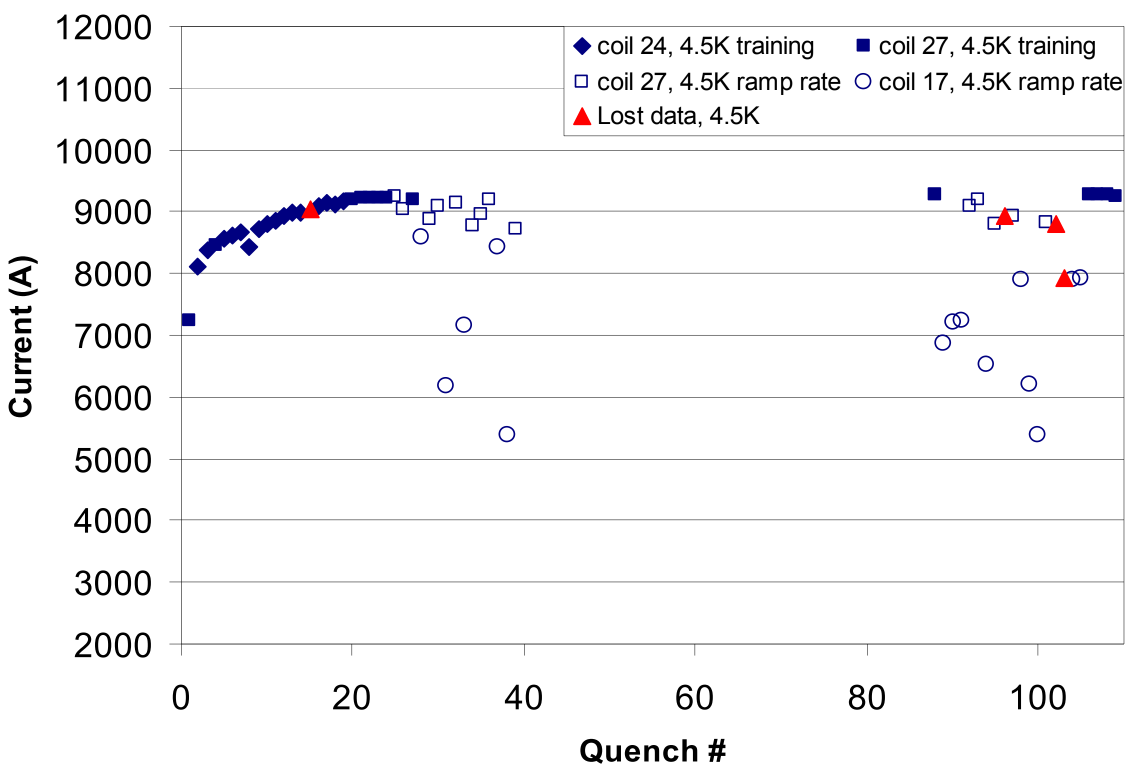

Figure 3. TQC02a quench history at 4.5 K.

All quenches from the cold test at 1.9 K are shown in Fig.4. Training at 1.9 K showed rather erratic quench performance. Only coils 24 and 27 were quenching and the quench current varied from ~ 8.5 kA to ~ 9 kA without any indication of training. Therefore we started the ramp rate study at 1.9 K and found very soon that the quench current increased at higher ramp rates, 50-200 A/s. Moreover, the magnet exhibited training during the ramp rate study at 1.9 K and the quench current increased by ~ 400 A. For quench # 65 a ramp rate of 50 A/s was used ramping-up to 9.2 kA followed by the normal training ramp rate of 20 A/s: we reached a quench current of ~ 9700 A, almost 1 kA more than the previous 20 A/s quenches. Quenches moved to coils 17 and 19 at the highest ramp rates.

At quench # 56 we tried to test the spot heater, but firing it at the magnet current of 8200 A did not result in quench. We then tried to increase the heater supply voltage from 30 V to 40 V but the spot heater circuit was found to have opened up (inside the dewar).

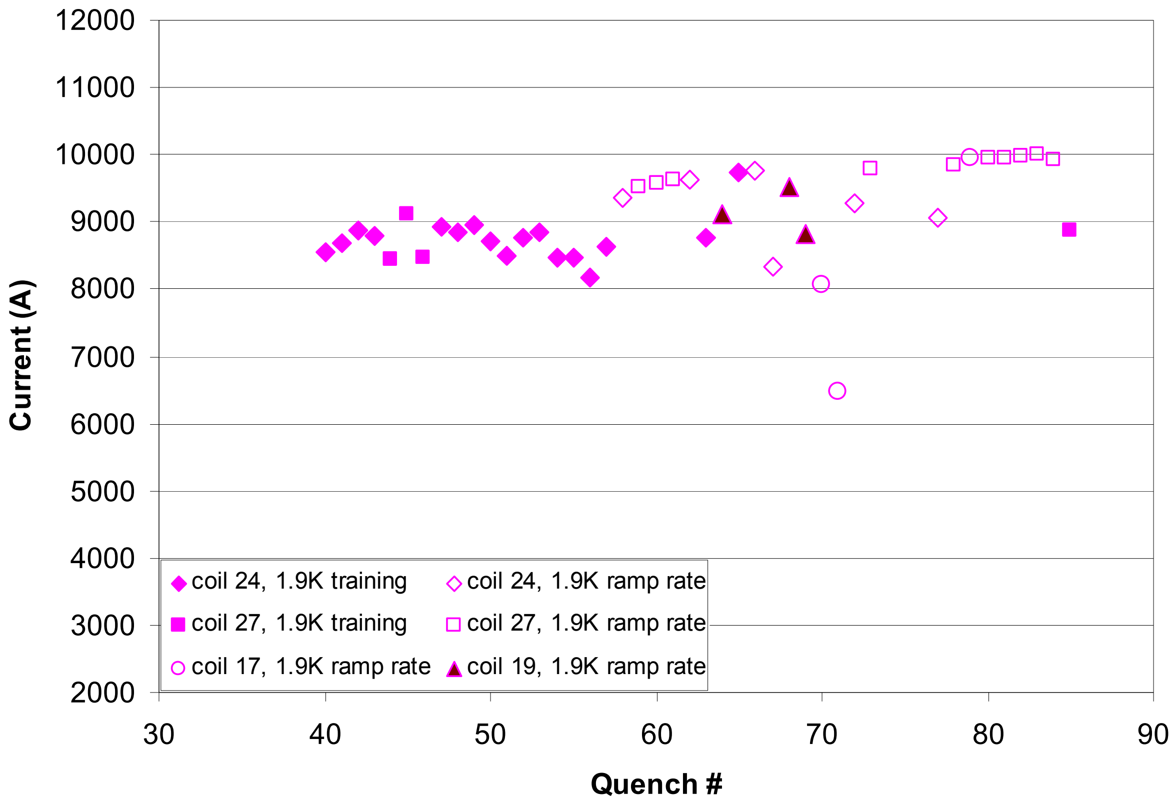

Figure 4. TQC02a quench history at 1.9 K.

At the end of the cold test we confirmed the quench current plateau at 4.5 K was consistent with the 4.5 K performance in the beginning of the test: the quench current increased slightly, by about 50-60 A, after training at 1.9 K.

The highest quench current achieved was 9264 A at 4.5 K (the quench # 108 at 20 A/s ramp rate) and 10009 A at 1.9 K (the quench # 83 at 50 A/s ramp rate). The complete quench history is shown in Fig.5 and presented in Tables 1 and 2.

All training quenches were located in the inner layer of the coils, mostly at the return end of magnet. High ramp rate quenches were located in the mid-plane segments. Quench locations will be discussed in detail in Section 9. The training quenches developed only in coils 24 and 27, while coils 17 and 19 were quenching only at high ramp rates, i.e. during the ramp rate study (see Fig.6).

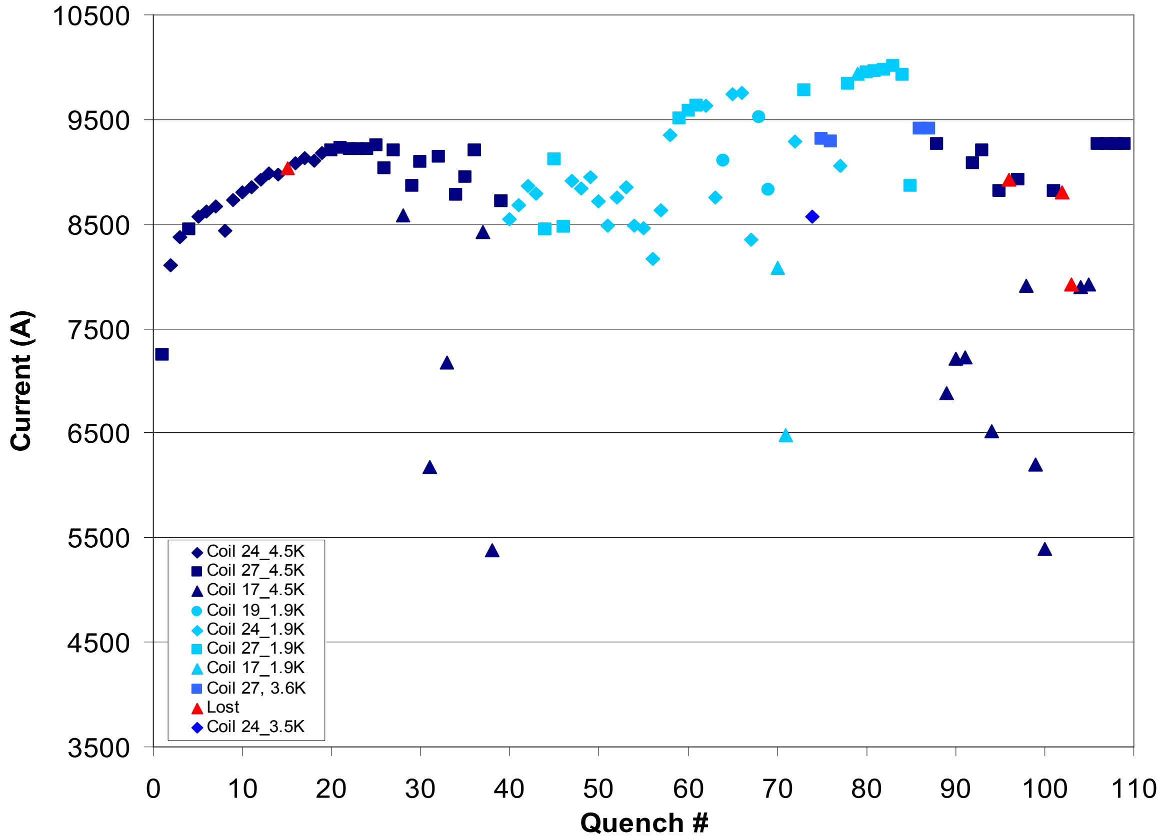

Figure 5. TQC02a quench history.

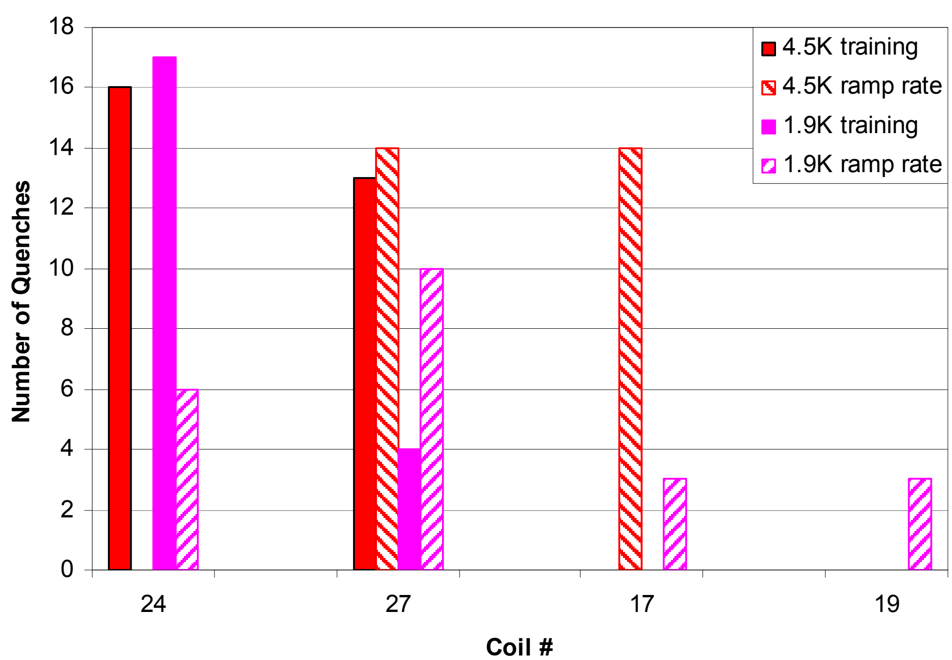

Figure 6. Quench multiplicity in coils for the training quenches and the ramp rate study

We lost *Pentek* quench data for quenches # 15, 96, 102 and 103, all at 4.5 K. No particular reasons were found for these failures (possibly network communication errors or other *Pentek* crashes; a *VME* bus analyzer did not detect *VME* bus errors).

The field quality magnetic measurements were made at different temperatures. A set of the "warm" magnetic measurements (z-scan) at 300 K was performed on February 1st. We encountered problems with the limit switch on the VMTF vertical drive system that prevented vertical motion of the probe. To fix this problem the bottom "forward" limit switch was jumpered to the ground. Magnetic measurements also were made at 4.5 K on February 5th and at 1.9 K on February 14th. Results of these measurements are summarized in Section 8.

4. Ramp Rate Dependence

Several quenches were performed for the ramp rate dependence study at 4.5 K and 1.9 K. A plot summarizing all ramp rate quenches is shown in Fig.7.

At 4.5 K we see quench current smoothly decreases with increasing the ramp rate up to 200-212 A/s. In this region the ramp rate dependence exhibits a "knee" with a sharp decline - this seems indicate significant degradation in coil 27, which limited the magnet quench performance at 4.5 K. At the high ramp rates (200 A/s and more) the 4.5 K quenches developed in coil 17.

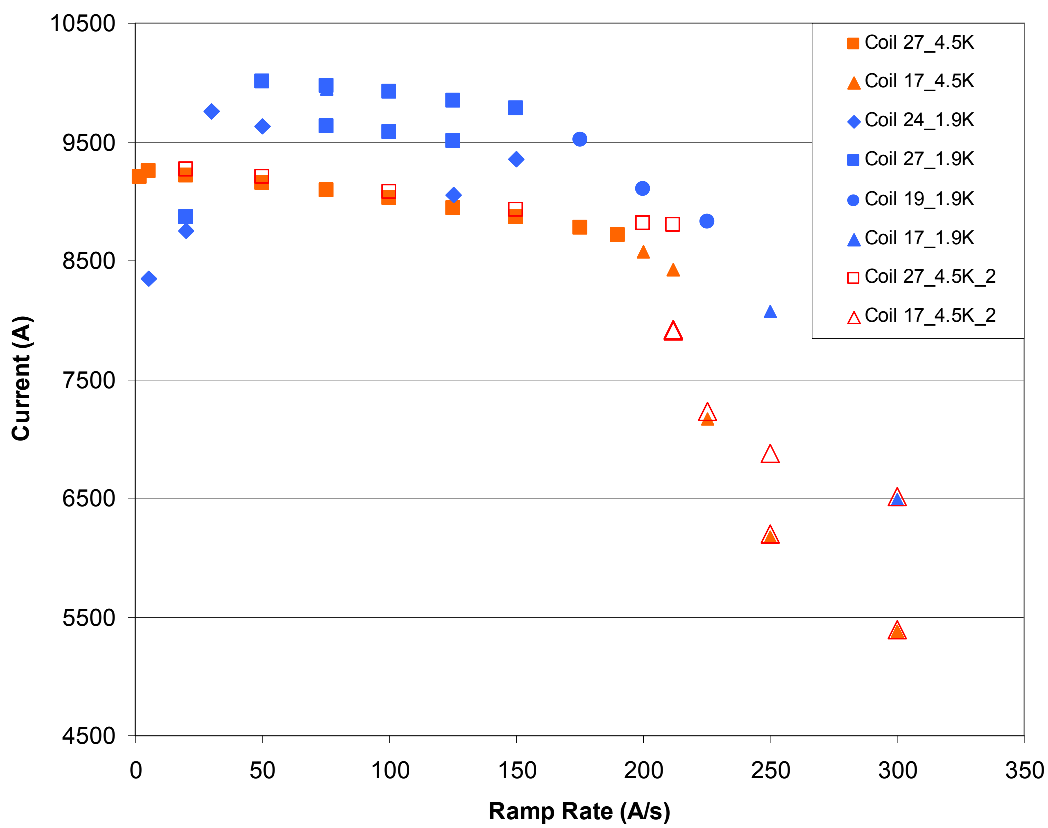

Figure 7. Ramp rate study at 4.5 K and 1.9 K

Table 1: TQC02a Quench History with comments

File	Q#	Current (A)	dI/dt (A/sec)	t_{quench}	MIITs	QDC	Ave Temp (K)	Mag Temp Bot (K)	Mag Temp Top (K)	Comments [notes in brackets were added later]
tqc02a.Quench.080205152030.960	-	4999	0	-0.043	2.86	HcoilHcoil	4.45	4.45	4.45	HFU2 induced trip at 5kA. 4.4K. Dump delay 25ms, HFU1/2 at 300V, strip heater delay 0ms.
tqc02a.Quench.080205155113.839	-	5001	0	-0.048	2.94	WcoilIdot	4.45	4.45	4.45	HFU1 induced trip at 5000A, dump delay 25ms, both HFU at 300V, strip heater delay 0ms.
tqc02a.Quench.080206105342.763	-	5915	20	0.000	1.61	WcoilGnd	4.45	4.45	4.45	[Cu-leads tripped, AQD/DQD cl rebalanced]
tqc02a.Quench.080206114747.766	**1**	7252	20	-0.033	4.14	HcoilHcoil	4.45	4.45	4.46	quench at 7245.1A, 20A/s, 4.5K
tqc02a.Quench.080206123258.523	**2**	8098	20	-0.458	32.90	HcoilHcoil	4.45	4.45	4.45	quench at 8105.1A, 20A/s, 4.5K.
tqc02a.Quench.080206131410.270	**3**	8379	20	-0.021	4.40	HcoilHcoil	4.44	4.45	4.44	quench at 8373A, 20A/s, 4.5K
tqc02a.Quench.080206134400.408	**4**	8450	20	-0.016	4.11	HcoilHcoil	4.45	4.45	4.45	ramp5, 20 A/s, 4,5K, 40mV VSDS threshold
tqc02a.Quench.080206141215.423	**5**	8568	20	-0.412	33.24	HcoilHcoil	4.44	4.44	4.44	ramp 6, 20 A/s, 4.5K, 40mV vsds threshold
tqc02a.Quench.080206144318.473	**6**	8621	20	-0.018	4.38	HcoilHcoil	4.45	4.45	4.45	ramp 7, 20 A/s, 4.5K train. quench 6
tqc02a.Quench.080206151515.177	**7**	8677	20	-0.017	4.35	HcoilHcoil	4.45	4.45	4.45	quench at 8672.4A, 20A/s, 4.5K
tqc02a.Quench.080206154621.427	**8**	8434	20	-0.472	36.53	HcoilHcoil	4.45	4.45	4.45	quench at 8435.9A, 20A/s, 4.5K.
tqc02a.Quench.080206161844.872	**9**	8732	20	-0.016	4.25	HcoilHcoil	4.45	4.45	4.45	quench at 8726A, 20A/s, 4.5K.□h
tqc02a.Quench.080206165335.003	**10**	8805	20	-0.015	4.25	HcoilHcoil	4.45	4.45	4.45	quench at 8800.6A, 20A/s, 4.5K.
tqc02a.Quench.080206173103.010	**11**	8858	20	-0.162	15.84	HcoilHcoil	4.45	4.44	4.45	quench at 8854.3A, 20A/s, 4.5K.
tqc02a.Quench.080206181229.760	**12**	8918	20	-0.322	28.72	HcoilHcoil	4.44	4.44	4.44	quench at 8919.5A, 20A/s, 4.5K
tqc02a.Quench.080206184923.625	**13**	8991	20	-0.296	27.12	HcoilHcoil	4.44	4.44	4.44	quench at 8988A, 20A/s, 4.5K
tqc02a.Quench.080206194008.398	**14**	8980	20	-0.015	4.35	HcoilHcoil	4.45	4.45	4.45	quench at 8975A, 20A/s, 4.5K.
tqc02a.Quench.080207111612.533	**15**	9038	20	----	----	------------	4.44	4.44	4.44	*[from eLog: Data loggers lost communication with vxf when trying to save quench data, so we lost data for quench #15]*
tqc02a.Quench.080207120853.630	**16**	9089	20	-0.012	4.14	HcoilHcoil	4.45	4.44	4.45	quench at 9080.6A, 20A/s, 4.5K.

tqc02a.Quench.080207125919.392	**17**	9141	20	-0.007	3.80	WcoilIdot	4.45	4.45	4.45	quench at 9131.8A, 20A/s, 4.5K
tqc02a.Quench.080207132938.102	**18**	9118	20	-0.012	4.14	HcoilHcoil	4.46	4.46	4.46	quench at 9111.7A, 20A/s, 4.5K.
tqc02a.Quench.080207135732.526	**19**	9183	20	-0.011	4.16	HcoilHcoil	4.45	4.45	4.45	ramp 20, 20 A/s, 4.45K training quench 10
tqc02a.Quench.080207142754.966	**20**	9211	20	-0.276	26.67	HcoilHcoil	4.46	4.46	4.45	ramp 21, 20A/s, 4.45K training quench 20
tqc02a.Quench.080207150106.513	**21**	9232	20	-0.007	3.86	HcoilHcoil	4.45	4.45	4.44	ramp 22, 20 A/s, 4.45K training quench 21
tqc02a.Quench.080207152935.457	**22**	9219	20	-0.007	3.84	HcoilHcoil	4.45	4.45	4.46	ramp 23, 20 A/s, 4.45K
tqc02a.Quench.080207160212.213	**23**	9224	20	-0.358	33.67	HcoilHcoil	4.45	4.45	4.45	quench at 9221.8A, 20A/s, 4.5K.
tqc02a.Quench.080207170556.492	**24**	9228	20	-0.007	3.88	HcoilHcoil	4.45	4.45	4.45	quench at 9220.3A, 20A/s, 4.5K.
tqc02a.Quench.080207175512.992	**25**	9260	**20**	-0.259	25.40	HcoilHcoil	4.45	4.45	4.44	quench at 9251.6A, 20A/s, 4.5K
tqc02a.Quench.080207185729.486	**26**	9043	100	-0.008	3.76	HcoilHcoil	4.44	4.44	4.44	quench at 9034.4A with ramp rate 100A/s. 4.5K.
tqc02a.Quench.080208090127.369	**27**	9214	20	-0.004	3.61	WcoilIdot	4.46	4.46	4.46	quench at 9205.6A, 20A/s with conditioning run: 50A/s upto 7500A and back to 0A. 4.5K.
tqc02a.Quench.080208111210.555	**28**	8589	200	-0.005	3.16	HcoilHcoil	4.45	4.45	4.45	quench at 8581.2A, 200A/s, 4.45K.
tqc02a.Quench.080208115859.937	**29**	8876	150	-0.009	3.77	HcoilHcoil	4.45	4.45	4.45	quench at 8868.3A, 150A/s, 4.5K
tqc02a.Quench.080208124948.141	**30**	9100	75	-0.006	3.66	HcoilHcoil	4.45	4.45	4.45	quench at 9kA, 75A/s. 4.5K.
tqc02a.Quench.080208132955.467	**31**	6172	250	-0.008	2.14	HcoilHcoil	4.45	4.45	4.45	quench at 6172.3A, ramp rate 250A/s. 4.5K.
tqc02a.Quench.080208135744.400	**32**	9157	50	-0.008	3.82	HcoilHcoil	4.44	4.44	4.44	ramp 33, 4.5K, 50 A/s ramp rate study
tqc02a.Quench.080208142511.312	**33**	7176	225	-0.007	2.61	HcoilHcoil	4.45	4.45	4.45	ramp 34, 4.45K, 225 A/s ramp rate study
tqc02a.Quench.080208145116.319	**34**	8688	175	-0.498	41.00	HcoilHcoil	4.45	4.45	4.45	ramp 35, 175 A/s ramp rate study at 4.45K
tqc02a.Quench.080208153423.812	**35**	8951	125	-0.012	4.02	HcoilHcoil	4.45	4.45	4.45	quench at 8946A, 125A/s, 4.5K
tqc02a.Quench.080208164747.846	**36**	9212	2	-0.122	13.49	HcoilHcoil	4.44	4.45	4.44	quench at 9206A with ramp rate 2A/s (50A/s upto 7kA). 4.5K.
tqc02a.Quench.080208174007.744	**37**	8431	212	-0.005	3.12	HcoilHcoil	4.45	4.45	4.45	quench at 8425A with ramp rate 212A/s. 4.5K
tqc02a.Quench.080208180731.216	**38**	5383	300	-0.009	1.74	HcoilHcoil	4.45	4.44	4.45	quench at 5382.5A, 300A/s, 4.5K
tqc02a.Quench.080208190406.243	**39**	8720	190	-0.013	3.86	HcoilHcoil	4.45	4.45	4.45	quench at 8715.5A, 190A/s, 4.5K.
tqc02a.Quench.080211105029.763	**40**	8553	20	-0.015	4.27	WcoilIdot	1.88	1.88	1.88	quench at 8544A with ramp rate 20A/s, 1.9K.

tqc02a.Quench.080211113048.469	**41**	8688	20	-0.020	4.64	HcoilHcoil	1.90	1.91	1.90	quench at 8679.7A, ramp rate 20A/s, 1.89K
tqc02a.Quench.080211120609.131	**42**	8875	20	-0.016	4.41	WcoilIdot	1.89	1.89	1.88	quench at 8865.8A, 20A/s, 1.9K.
tqc02a.Quench.080211124814.263	**43**	8788	20	-0.124	12.78	HcoilHcoil	1.90	1.89	1.90	quench at 8787A, 20A/s, 1.9K
tqc02a.Quench.080211131724.729	**44**	8441	20	-0.500	38.69	HcoilHcoil	1.89	1.90	1.89	1.878K, 20A/s training quench; VSDS threshold = 25mV (315 spike events)
tqc02a.Quench.080211134749.039	**45**	9130	20	-0.009	4.02	HcoilHcoil	1.87	1.87	1.87	1.88K 20A/s training, VSDS threshold =25mV
tqc02a.Quench.080211141716.576	**46**	8475	20	-0.354	28.47	HcoilHcoil	1.87	1.87	1.87	1.88K 20 A/s training quench at 8473.9, VSDS threshold=25mV
tqc02a.Quench.080211144808.267	**47**	8922	20	-0.019	4.72	HcoilHcoil	1.88	1.88	1.88	1.9K 20A/s training quench at 8914.1A, VSDS threshold = 25mV
tqc02a.Quench.080211153939.803	**48**	8844	20	-0.019	4.62	HcoilHcoil	1.89	1.89	1.89	quench at 8839.2A, 20A/s, 1.9K
tqc02a.Quench.080211162805.470	**49**	8958	20	-0.019	4.74	HcoilHcoil	1.89	1.88	1.89	quench at 8949.3A, 20A/s, 1.9K
tqc02a.Quench.080211171625.267	**50**	8714	20	-0.014	4.17	WcoilIdot	1.89	1.89	1.88	quench at 8711.8A, 20A/s, 1.9K
tqc02a.Quench.080211180255.941	**51**	8484	20	0.000	3.88	AQD_COIL	1.90	1.90	1.90	quench at 8484A, 20A/s, 1.9K; loggers hung and not read out; data lost
tqc02a.Quench.080211185119.648	**52**	8749	**20**	-0.575	47.19	HcoilHcoil	1.90	1.90	1.90	quench at 8752.5A, 20A/s, 1.9K.
tqc02a.Quench.080211192117.447	**53**	8862	20	-0.018	4.59	HcoilHcoil	1.90	1.90	1.90	quench at 8851A, 20A/s, 1.9K
tqc02a.Quench.080212085448.556	**54**	8485	20	-0.024	4.81	HcoilHcoil	1.85	1.86	1.85	quench at 8478.9A with ramp rate 20A/s. 1.9K
tqc02a.Quench.080212095317.778	**55**	8473	20	-0.024	4.73	HcoilHcoil	1.88	1.88	1.88	quench at 8465A, 20A/s with conditioning: 50A/s upto 7.5kA and back to 0A. 1.9K
tqc02a.Quench.080212104244.295	**56**	8171	-50	-0.026	4.60	HcoilHcoil	1.87	1.86	1.87	quench when ramping down at 50A/s. Spot heater did not fire and need to investigate
tqc02a.Quench.080212131315.721	**57**	8629	20	-0.067	8.14	HcoilHcoil	1.87	1.87	1.87	quench at 8632.1A, 20A/s, 1.9K
tqc02a.Quench.080212134300.197	**58**	9353	150	-0.010	4.08	HcoilHcoil	1.87	1.87	1.88	quench at 9352.1A with ramp rate 150A/s, 1.9K.
tqc02a.Quench.080212150957.688	**59**	9508	125	-0.054	8.25	HcoilHcoil	1.89	1.88	1.89	quench at 9508A with ramp rate 125A/s, 1.9K
tqc02a.Quench.080212154833.016	**60**	9582	100	-0.007	4.01	HcoilHcoil	1.90	1.90	1.90	quench at 9581A, 100A/s. 1.9K.
tqc02a.Quench.080212161957.655	**61**	9637	75	-0.011	4.41	WcoilGnd	1.88	1.88	1.88	quench at 9636.1A, 75A/s, 1.9K
tqc02a.Quench.080212170140.341	**62**	9636	50	-0.093	12.04	HcoilHcoil	1.90	1.90	1.90	quench at 9635A, 50A/s, 1.9K.

tqc02a.Quench.080212182913.322	**63**	8750	**20**	-0.600	49.09	HcoilHcoil	1.89	1.90	1.89	quench at 8757.4A, 20A/s, 1.9K
tqc02a.Quench.080213083806.631	**64**	9108	200	-0.004	3.52	HcoilHcoil	1.86	1.86	1.85	quench at 9107A, 200A/s, 1.9K
tqc02a.Quench.080213093724.974	**65**	9740	20	-0.006	4.05	HcoilHcoil	1.89	1.89	1.88	quench at 9738A, 20A/s (50A/s to 9.2kA), 1.9K
tqc02a.Quench.080213110301.344	**66**	9755	30	-0.012	4.58	HcoilHcoil	1.90	1.89	1.90	quench at 9751.8A, 30A/s, 1.9K
tqc02a.Quench.080213114022.131	**67**	8347	5	-0.456	34.72	HcoilHcoil	1.88	1.87	1.88	quench at 8343.9A, 5A/s (50A/s to 7.5kA), 1.9K
tqc02a.Quench.080213120152.786	**68**	9522	176	-0.005	3.71	HcoilHcoil	1.89	1.89	1.88	quench at 9521.9A, 175A/s, 1.9K
tqc02a.Quench.080213123147.223	**69**	8792	225	-0.154	14.86	HcoilHcoil	1.90	1.91	1.90	quench at 8824.6A, 225A/s, 1.9K.
tqc02a.Quench.080213125026.322	**70**	8039	250	-0.158	12.91	HcoilHcoil	1.89	1.89	1.89	quench at 8076.6A, 250A/s, 1.9K
tqc02a.Quench.080213131144.668	**71**	6300	300	-0.612	26.98	HcoilHcoil	1.88	1.88	1.88	quench at 6482A, 300A/s, 1.9K
tqc02a.Quench.080213134500.104	**72**	9288	5	-0.017	4.77	HcoilHcoil	1.92	1.92	1.91	another test at 1.9K, ramp at 50A/s to 9200 then 5A/s to quench at 9284.6 ramp number 741755442
tqc02a.Quench.080213153353.816	**73**	9763	150	-0.107	13.61	HcoilHcoil	1.92	1.93	1.91	1.9K ramp rate study, repeat 150 A/s - quench current went up, which indicates we are still training !
tqc02a.Quench.080213173018.970	**74**	8571	20	-0.016	4.21	WcoilIdot	2.88	2.55	3.21	quench at 8569.7A, 20A/s, T=3.2K at top and 2.5K at bottom of the magnet
tqc02a.Quench.080213175051.842	**75**	9320	100	-0.006	3.73	HcoilHcoil	3.27	2.60	3.95	quench at 9318.3A, 100A/s, T=(3.9K/2.6K top/bottom)
tqc02a.Quench.080213181309.891	**76**	9293	100	-0.005	3.65	HcoilHcoil	3.46	2.66	4.27	quench at 9294A, 100A/s, T=4.28K/2.66K (top/bottom)
tqc02a.Quench.080214154954.125	**77**	9062	125	-0.022	5.09	HcoilHcoil	1.92	1.93	1.92	quench at 9056A, 125A/s, 1.9K, first quench after the magnetic measurements
tqc02a.Quench.080214162202.079	**78**	9846	125	-0.003	3.73	HcoilHcoil	1.89	1.88	1.89	quench at 9842.4A, 125A/s, 1.9K
tqc02a.Quench.080214170127.621	**79**	9946	75	-0.011	4.58	WcoilGnd	1.87	1.87	1.87	quench at 9944.1A, 75A/s, 1.9K
tqc02a.Quench.080214173725.216	**80**	9947	75	-0.126	15.97	HcoilHcoil	1.90	1.90	1.91	quench at 9952.4A, 75A/s, 1.9K
tqc02a.Quench.080214182919.220	**81**	9923	75	-0.595	62.36	HcoilHcoil	1.90	1.89	1.90	quench at 9963.1A, 75A/s, 1.9K
tqc02a.Quench.080214185331.854	**82**	9980	75	-0.004	3.88	HcoilHcoil	1.87	1.87	1.87	quench at 9975.5A, 75A/s, 1.9Kx
tqc02a.Quench.080214192930.917	**83**	10010	50	-0.005	3.97	HcoilHcoil	1.89	1.89	1.89	quench at 10008.8A, 50A/s, 1.9K
tqc02a.Quench.080215082306.312	**84**	9930	100	-0.003	3.83	HcoilHcoil	1.85	1.85	1.86	quench at 9926.5A, 100A/s, 1.9K
tqc02a.Quench.080215085646.020	**85**	8856	20	-0.431	37.03	HcoilHcoil	1.91	1.90	1.91	quench at 8862.7A, 20A/s, 1.9K.

tqc02a.Quench.080215104838.292		5048	50	0.000	1.36	WcoilGnd	3.52	3.50	3.53	Leads tripped at 5kA, LHe flow problem
tqc02a.Quench.080215111609.642	**86**	9413	20	-0.003	3.64	WcoilIdot	3.65	3.62	3.67	quench at 9411.2A, 20A/s, 3.6K
tqc02a.Quench.080215121849.836	**87**	9412	20	-0.004	3.70	HcoilHcoil	3.60	3.53	3.68	quench at 9413.4A, 20A/s, 3.66K/3.51K.
tqc02a.Quench.080215135900.793	**88**	9264	20	-0.004	3.61	WcoilIdot	4.45	4.45	4.45	returned to 4.5K, 20A/s to check quench performance after training at 1.9K and temperature dependence study. ramp 91, VSDS thresh=25mV
tqc02a.Quench.080215174143.635	**89**	6879	250	-0.006	2.47	HcoilHcoil	4.45	4.46	4.45	directly following a series of EIEO measurements at various ramp rates, we performed a ramp to quench at 250 A/s, 4.5K.
tqc02a.Quench.080215180535.088	**90**	7216	225	-0.006	2.60	HcoilHcoil	4.45	4.45	4.45	quench at 7213.9A, 225A/s, 4.45K.
tqc02a.Quench.080215182115.197	**91**	7230	225	-0.006	2.61	HcoilHcoil	4.46	4.45	4.46	quench at 7230.6A, 225A/s, 4.45K
tqc02a.Quench.080218102810.048	**92**	9080	100	-0.018	4.74	HcoilHcoil	4.45	4.45	4.45	quench at 9080.1A, 100A/s, 4.45K
tqc02a.Quench.080218105837.507	**93**	9196	50	-0.153	16.11	HcoilHcoil	4.45	4.45	4.45	quench at 9201.3A, 50A/s, 4.45K
tqc02a.Quench.080218180952.177	**94**	6514	**300**	-0.007	2.29	HcoilHcoil	4.45	4.45	4.45	quench at 6514.6A, 300A/s, 4.5K
tqc02a.Quench.080218185730.931	**95**	8747	**200**	-0.424	35.64	HcoilHcoil	4.45	4.45	4.45	quench at 8811.4A, 200A/s, 4.5K
tqc02a.Quench.080220115439.573	**-**	999	0	0.013	0.95	WcoilGnd	4.44	4.44	4.44	another trip at 1000A
tqc02a.Quench.080220120553.812	**-**	5391	150	-0.402	13.42	HcoilHcoil	4.44	4.44	4.43	we tripped at 5452A when ramping up at 150A/s
tqc02a.Quench.080221140343.404	**-**	1358	50	0.001	0.11	WcoilGnd	4.45	4.45	4.44	manual trip around 1000A during ramping
tqc02a.Quench.080221141355.280	**-**	1085	0	0.001	0.09	WcoilGnd	4.44	4.44	4.44	manual trip at 1000A
tqc02a.Quench.080221142203.903	**-**	1129	165	-0.215	0.40	HcoilHcoil	4.43	4.44	4.43	trip at ramping, 300A/s
tqc02a.Quench.080221145302.082	**-**	1129	50	0.001	0.10	WcoilIdot	4.44	4.44	4.44	50A/s manual trip at around 1000A. Ground fault simulated
tqc02a.Quench.080221150353.621	**-**	987	0	-0.577	0.72	HcoilHcoil	4.44	4.44	4.44	1ohms ground fault, manual trip ~1000A, 300A/s
tqc02a.Quench.080221152029.144	**-**	972	50	0.001	0.10	WcoilGnd	4.44	4.44	4.44	10Ohms ground fault. 50A/s
tqc02a.Quench.080221153711.808	**-**	1304	154	0.001	0.12	WcoilGnd	4.44	4.44	4.43	10Ohms ground fault, 300A/s trip
tqc02a.Quench.080221182943.808	**96**	8925	150	0.000	0.00		4.50	4.50	4.50	quench at 8924.6A, 150A/s, 4.5K [Data lost, input from eLog]

tqc02a.Quench.080221192616.674	**97**	8934	150	-0.010	3.87	HcoilHcoil	4.44	4.44	4.44	quench at 8926.6A, 150A/s, 4.5K
tqc02a.Quench.080222081639.733	**98**	7922	212	-0.006	2.96	HcoilHcoil	4.45	4.44	4.45	quench at 7912.3A, 212A/s, 4.45K
tqc02a.Quench.080222083155.933	**99**	6205	250	-0.007	2.13	HcoilHcoil	4.45	4.45	4.45	quench at 6199A, 250A/s, 4.5K
tqc02a.Quench.080222085324.940	**100**	5396	300	-0.009	1.75	HcoilHcoil	4.43	4.44	4.43	quench at 5396.2A, 300A/s, 4.45K
tqc02a.Quench.080222091930.767	**101**	8817	156	-0.011	3.84	HcoilHcoil	4.44	4.44	4.43	quench at 8815A, 200A/s, 4.45K
tqc02a.Quench.080222142136.757.	**102**	8807	212	0.000	0.00		0.00	0.00	0.00	attempted IMMW probe quench antenna test, but cannot save logger data; Iq = 8807.1, ramp was 212 A/s following 1.5hour IMMW probe zscan at 6500A
tqc02a.Quench.080222144900.368	**103**	7923	212	0.000	0.00		0.00	0.00	0.00	212 A/s ramp to quench, no pre-ramps, quench at 7923.4A IMMW quench antenna probe is in same position, repeat after lost data.In fact, it appears that logger is having trouble saving data again.
tqc02a.Quench.080222154346.367	**104**	7904	212	-0.006	2.92	HcoilHcoil	4.44	4.44	4.43	quench at 7902.7A, 212A/s, 4.45K
tqc02a.Quench.080222161128.117	**105**	7928	212	-0.007	3.04	HcoilHcoil	4.43	4.43	4.43	quench at 7925.5A, 212A/s. 4.45K
tqc02a.Quench.080222164105.151	**106**	9272	20	-0.007	3.85	HcoilHcoil	4.43	4.44	4.43	quench at 9268A, 20A/s, 4.45K
tqc02a.Quench.080222171633.530	**107**	9266	20	-0.007	3.84	HcoilHcoil	4.44	4.43	4.44	20 A/s 4.45K. IMMW probe quench antenna moved down 20cm, and DQbucked signal moved to pins AB (from CD).
tqc02a.Quench.080222174547.092	**108**	9270	20	-0.007	3.84	HcoilHcoil	4.44	4.44	4.44	Quench at 9263.9A, 20Aa/s, 4.45K. IMMW probe shifted up for 10cm (current position is -0.1m)
tqc02a.Quench.080222182253.926	**109**	9266	20	-0.006	3.73	HcoilHcoil	4.43	4.44	4.43	quench at 9261.4A, 20A/s, 4.45K. IMMW probe at -0.3m

Table 2: TQC02a Quench History with parameters for the first two quenching segments

File	Q#	Current (A)	dI/dt (A/sec)	t_{quench}	MIITs	QDC	1st VTseg	t_{rise}	2nd VTseg	t_{rise}	Mag Temp Bot (K)	Mag Temp Top (K)
tqc02a.Quench.080205152030.960	-	4999	0	-0.043	2.86	HcoilHcoil	17b3_17b2	-0.042	19b3_19b2	-0.042	4.454	4.454
tqc02a.Quench.080205155113.839	-	5001	0	-0.048	2.94	WcoilIdot	27b2_27b3	-0.047	17b3_27b2	-0.046	4.446	4.451
tqc02a.Quench.080206105342.763	-	5915	20	0.000	1.61	WcoilGnd	V1_TrigFvtB1	0.000	V1_TrigCvtB1	0.000	4.448	4.447
tqc02a.Quench.080206114747.766	**1**	7252	20	-0.033	4.14	HcoilHcoil	27a8_27a7	-0.034	27a6_27a5	-0.019	4.448	4.458
tqc02a.Quench.080206123258.523	**2**	8098	20	-0.458	32.90	HcoilHcoil	24a10_24a9	-0.020	24a9_24a8	-0.018	4.446	4.453
tqc02a.Quench.080206131410.270	**3**	8379	20	-0.021	4.40	HcoilHcoil	24a10_24a9	-0.019	24a9_24a8	-0.019	4.447	4.441
tqc02a.Quench.080206134400.408	**4**	8450	20	-0.016	4.11	HcoilHcoil	27a8_27a7	-0.018	27a6_27a5	-0.016	4.448	4.450
tqc02a.Quench.080206141215.423	**5**	8568	20	-0.412	33.24	HcoilHcoil	24a10_24a9	-0.019	24a6_24a5	-0.012	4.445	4.442
tqc02a.Quench.080206144318.473	**6**	8621	20	-0.018	4.38	HcoilHcoil	24a10_24a9	-0.020	24a6_24a5	-0.014	4.454	4.452
tqc02a.Quench.080206151515.177	**7**	8677	20	-0.017	4.35	HcoilHcoil	24a10_24a9	-0.014	24a6_24a5	-0.011	4.447	4.446
tqc02a.Quench.080206154621.427	**8**	8434	20	-0.472	36.53	HcoilHcoil	24a10_24a9	-0.016	24a6_24a5	-0.011	4.446	4.447
tqc02a.Quench.080206161844.872	**9**	8732	20	-0.016	4.25	HcoilHcoil	24a10_24a9	-0.014	24a8_24a7	-0.009	4.449	4.454
tqc02a.Quench.080206165335.003	**10**	8805	20	-0.015	4.25	HcoilHcoil	24a8_24a7	-0.015	24a6_24a5	-0.013	4.446	4.448
tqc02a.Quench.080206173103.010	**11**	8858	20	-0.162	15.84	HcoilHcoil	24a6_24a5	-0.015	24a10_24a9	-0.013	4.444	4.447
tqc02a.Quench.080206181229.760	**12**	8918	20	-0.322	28.72	HcoilHcoil	24a6_24a5	-0.015	24a10_24a9	-0.014	4.441	4.443
tqc02a.Quench.080206184923.625	**13**	8991	20	-0.296	27.12	HcoilHcoil	24a10_24a9	-0.016	24a6_24a5	-0.008	4.445	4.440
tqc02a.Quench.080206194008.398	**14**	8980	20	-0.015	4.35	HcoilHcoil	24a10_24a9	-0.016	24a6_24a5	-0.008	4.448	4.451
tqc02a.Quench.080207111612.533	**15**	9038	20	----	----	------------	------------	----	------------	----	4.440	4.440
tqc02a.Quench.080207120853.630	**16**	9089	20	-0.012	4.14	HcoilHcoil	24a10_24a9	-0.009	24a8_24a7	-0.009	4.441	4.450
tqc02a.Quench.080207125919.392	**17**	9141	20	-0.007	3.80	WcoilIdot	24a10_24a9	-0.012	24a6_24a5	-0.012	4.447	4.448
tqc02a.Quench.080207132938.102	**18**	9118	20	-0.012	4.14	HcoilHcoil	24a10_24a9	-0.011	24a6_24a5	-0.011	4.456	4.457

tqc02a.Quench.080207135732.526	**19**	9183	20	-0.011	4.16	HcoilHcoil	24a10_24a9	-0.011	24a6_24a5	-0.010	4.454	4.455
tqc02a.Quench.080207142754.966	**20**	9211	20	-0.276	26.67	HcoilHcoil	27a8_27a7	-0.009	27a9_27a8	-0.009	4.456	4.455
tqc02a.Quench.080207150106.513	**21**	9232	20	-0.007	3.86	HcoilHcoil	27a9_27a8	-0.008	27a8_27a7	-0.008	4.450	4.442
tqc02a.Quench.080207152935.457	**22**	9219	20	-0.007	3.84	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.452	4.456
tqc02a.Quench.080207160212.213	**23**	9224	20	-0.358	33.67	HcoilHcoil	27a8_27a7	-0.009	27a9_27a8	-0.009	4.450	4.454
tqc02a.Quench.080207170556.492	**24**	9228	20	-0.007	3.88	HcoilHcoil	27a9_27a8	-0.010	27a8_27a7	-0.008	4.445	4.455
tqc02a.Quench.080207175512.992	**25**	9260	**20**	-0.259	25.40	HcoilHcoil	27a9_27a8	-0.009	27a8_27a7	-0.009	4.450	4.444
tqc02a.Quench.080207185729.486	**26**	9043	100	-0.008	3.76	HcoilHcoil	27a8_27a7	-0.009	27a9_27a8	-0.009	4.444	4.442
tqc02a.Quench.080208090127.369	**27**	9214	20	-0.004	3.61	WcoilIdot	27a9_27a8	-0.010	27a8_27a7	-0.009	4.460	4.461
tqc02a.Quench.080208111210.555	**28**	8589	200	-0.005	3.16	HcoilHcoil	17b3_17b2	-0.006	17a3_17a2	-0.006	4.446	4.449
tqc02a.Quench.080208115859.937	**29**	8876	150	-0.009	3.77	HcoilHcoil	27a8_27a7	-0.011	27a9_27a8	-0.011	4.450	4.452
tqc02a.Quench.080208124948.141	**30**	9100	75	-0.006	3.66	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.446	4.449
tqc02a.Quench.080208132955.467	**31**	6172	250	-0.008	2.14	HcoilHcoil	17b3_17b2	-0.007	17a3_17a2	-0.007	4.450	4.452
tqc02a.Quench.080208135744.400	**32**	9157	50	-0.008	3.82	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.440	4.440
tqc02a.Quench.080208142511.312	**33**	7176	225	-0.007	2.61	HcoilHcoil	17a9_17a10	-0.007	17a3_17a4	-0.006	4.452	4.453
tqc02a.Quench.080208145116.319	**34**	8688	175	-0.498	41.00	HcoilHcoil	27a9_27a8	-0.013	27a8_27a7	-0.013	4.453	4.454
tqc02a.Quench.080208153423.812	**35**	8951	125	-0.012	4.02	HcoilHcoil	27a9_27a8	-0.010	27a8_27a7	-0.009	4.446	4.446
tqc02a.Quench.080208164747.846	**36**	9212	2	-0.122	13.49	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.447	4.441
tqc02a.Quench.080208174007.744	**37**	8431	212	-0.005	3.12	HcoilHcoil	17a9_17a10	-0.006	17a2_17a3	-0.005	4.446	4.453
tqc02a.Quench.080208180731.216	**38**	5383	300	-0.009	1.74	HcoilHcoil	17b3_17b2	-0.009	17a3_17a2	-0.009	4.444	4.451
tqc02a.Quench.080208190406.243	**39**	8720	190	-0.013	3.86	HcoilHcoil	27a8_27a7	-0.012	27a9_27a8	-0.012	4.447	4.447
tqc02a.Quench.080211105029.763	**40**	8553	20	-0.015	4.27	WcoilIdot	24a10_24a9	-0.023	24a6_24a5	-0.015	1.882	1.876
tqc02a.Quench.080211113048.469	**41**	8688	20	-0.020	4.64	HcoilHcoil	24a10_24a9	-0.021	24a6_24a5	-0.013	1.908	1.898
tqc02a.Quench.080211120609.131	**42**	8875	20	-0.016	4.41	WcoilIdot	24a10_24a9	-0.020	24a6_24a5	-0.013	1.893	1.883
tqc02a.Quench.080211124814.263	**43**	8788	20	-0.124	12.78	HcoilHcoil	24a10_24a9	-0.019	24a6_24a5	-0.013	1.894	1.901
tqc02a.Quench.080211131724.729	**44**	8441	20	-0.500	38.69	HcoilHcoil	24a6_24a5	-0.015	27a8_27a7	-0.015	1.897	1.889
tqc02a.Quench.080211134749.039	**45**	9130	20	-0.009	4.02	HcoilHcoil	27a10_27a9	-0.013	24a6_24a5	-0.009	1.872	1.873
tqc02a.Quench.080211141716.576	**46**	8475	20	-0.354	28.47	HcoilHcoil	27a8_27a7	-0.015	27a9_27a8	-0.014	1.868	1.871
tqc02a.Quench.080211144808.267	**47**	8922	20	-0.019	4.72	HcoilHcoil	24a10_24a9	-0.018	24a6_24a5	-0.010	1.880	1.877
tqc02a.Quench.080211153939.803	**48**	8844	20	-0.019	4.62	HcoilHcoil	24a10_24a9	-0.019	24a6_24a5	-0.011	1.893	1.892

tqc02a.Quench.080211162805.470	**49**	8958	20	-0.019	4.74	HcoilHcoil	24a10_24a9	-0.018	24a6_24a5	-0.010	1.880	1.892
tqc02a.Quench.080211171625.267	**50**	8714	20	-0.014	4.17	WcoilIdot	24a10_24a9	-0.021	24a6_24a5	-0.012	1.888	1.883
tqc02a.Quench.080211180255.941	**51**	8484	20	0.000	3.88	AQD_COIL	------------	----	------------	----	1.900	1.900
tqc02a.Quench.080211185119.648	**52**	8749	**20**	-0.575	47.19	HcoilHcoil	24a10_24a9	-0.023	24a6_24a5	-0.011	1.898	1.899
tqc02a.Quench.080211192117.447	**53**	8862	20	-0.018	4.59	HcoilHcoil	24a10_24a9	-0.021	24a6_24a5	-0.011	1.901	1.897
tqc02a.Quench.080212085448.556	**54**	8485	20	-0.024	4.81	HcoilHcoil	24a10_24a9	-0.023	24a6_24a5	-0.014	1.858	1.851
tqc02a.Quench.080212095317.778	**55**	8473	20	-0.024	4.73	HcoilHcoil	24a10_24a9	-0.023	24a6_24a5	-0.014	1.879	1.875
tqc02a.Quench.080212104244.295	**56**	8171	-26	-0.026	4.60	HcoilHcoil	24a10_24a9	-0.024	24a6_24a5	-0.014	1.863	1.870
tqc02a.Quench.080212131315.721	**57**	8629	20	-0.067	8.14	HcoilHcoil	24a10_24a9	-0.021	24a6_24a5	-0.012	1.873	1.873
tqc02a.Quench.080212134300.197	**58**	9353	150	-0.010	4.08	HcoilHcoil	24a8_24a7	-0.012	24a10_24a9	-0.009	1.872	1.876
tqc02a.Quench.080212150957.688	**59**	9508	125	-0.054	8.25	HcoilHcoil	27a8_27a7	-0.009	27a9_27a8	-0.008	1.885	1.890
tqc02a.Quench.080212154833.016	**60**	9582	100	-0.007	4.01	HcoilHcoil	27a10_27a9	-0.010	27a8_27a7	-0.009	1.904	1.895
tqc02a.Quench.080212161957.655	**61**	9637	75	-0.011	4.41	WcoilGnd	27a10_27a9	-0.011	27a6_27a5	-0.007	1.882	1.876
tqc02a.Quench.080212170140.341	**62**	9636	49	-0.093	12.04	HcoilHcoil	24a10_24a9	-0.014	24a6_24a5	-0.008	1.898	1.904
tqc02a.Quench.080212182913.322	**63**	8750	**20**	-0.600	49.09	HcoilHcoil	24a10_24a9	-0.023	24a7_24a6	-0.013	1.896	1.888
tqc02a.Quench.080213083806.631	**64**	9108	200	-0.004	3.52	HcoilHcoil	19a2_19a3	-0.006	19b3_19b2	-0.006	1.860	1.853
tqc02a.Quench.080213093724.974	**65**	9740	19	-0.006	4.05	HcoilHcoil	24a10_24a9	-0.007	24a7_24a6	-0.006	1.889	1.884
tqc02a.Quench.080213110301.344	**66**	9755	30	-0.012	4.58	HcoilHcoil	24a10_24a9	-0.011	24a7_24a6	-0.010	1.895	1.903
tqc02a.Quench.080213114022.131	**67**	8347	5	-0.456	34.72	HcoilHcoil	24a10_24a9	-0.025	24a6_24a5	-0.014	1.874	1.881
tqc02a.Quench.080213120152.786	**68**	9522	176	-0.005	3.71	HcoilHcoil	19a2_19a3	-0.007	19b3_19b2	-0.007	1.891	1.881
tqc02a.Quench.080213123147.223	**69**	8792	225	-0.154	14.86	HcoilHcoil	19a2_19a3	-0.005	19b3_19b2	-0.005	1.908	1.898
tqc02a.Quench.080213125026.322	**70**	8039	250	-0.158	12.91	HcoilHcoil	17a9_17a10	-0.005	17a8_17a9	-0.004	1.888	1.892
tqc02a.Quench.080213131144.668	**71**	6300	300	-0.612	26.98	HcoilHcoil	17a2_17a3	-0.007	17a3_17a4	-0.007	1.883	1.882
tqc02a.Quench.080213134500.104	**72**	9288	5	-0.017	4.77	HcoilHcoil	24a10_24a9	-0.016	24b6_24a10	-0.013	1.918	1.914
tqc02a.Quench.080213153353.816	**73**	9763	150	-0.107	13.61	HcoilHcoil	27a8_27a7	-0.006	27a9_27a8	-0.006	1.932	1.914
tqc02a.Quench.080213173018.970	**74**	8571	20	-0.016	4.21	WcoilIdot	24a10_24a9	-0.022	24a6_24a5	-0.014	2.549	3.207
tqc02a.Quench.080213175051.842	**75**	9320	100	-0.006	3.73	HcoilHcoil	27a9_27a8	-0.009	27a8_27a7	-0.009	2.598	3.948
tqc02a.Quench.080213181309.891	**76**	9293	100	-0.005	3.65	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	2.659	4.268

tqc02a.Quench.080214154954.125	**77**	9062	125	-0.022	5.09	HcoilHcoil	24a10_24a9	-0.017	24a6_24a5	-0.011	1.927	1.917
tqc02a.Quench.080214162202.079	**78**	9846	125	-0.003	3.73	HcoilHcoil	27a9_27a8	-0.007	27a8_27a7	-0.007	1.885	1.889
tqc02a.Quench.080214170127.621	**79**	9946	75	-0.011	4.58	WcoilGnd	17a7_17a8	-0.015	17a6_17a7	-0.013	1.870	1.874
tqc02a.Quench.080214173725.216	**80**	9947	75	-0.126	15.97	HcoilHcoil	27a9_27a8	-0.006	27a8_27a7	-0.006	1.900	1.906
tqc02a.Quench.080214182919.220	**81**	9923	75	-0.595	62.36	HcoilHcoil	27a8_27a7	-0.007	27a9_27a8	-0.007	1.893	1.899
tqc02a.Quench.080214185331.854	**82**	9980	75	-0.004	3.88	HcoilHcoil	27a9_27a8	-0.006	27a8_27a7	-0.006	1.871	1.874
tqc02a.Quench.080214192930.917	**83**	10010	50	-0.005	3.97	HcoilHcoil	27a8_27a7	-0.006	27a9_27a8	-0.006	1.892	1.895
tqc02a.Quench.080215082306.312	**84**	9930	100	-0.003	3.83	HcoilHcoil	27a9_27a8	-0.007	27a8_27a7	-0.007	1.849	1.858
tqc02a.Quench.080215085646.020	**85**	8856	20	-0.431	37.03	HcoilHcoil	27a10_27a9	-0.013	27a7_27a6	-0.012	1.899	1.912
tqc02a.Quench.080215104838.292		5048	50	0.000	1.36	WcoilGnd	V1_TrigFvtB1	-0.001	17b1_27b1	-0.001	3.502	3.529
tqc02a.Quench.080215111609.642	**86**	9413	20	-0.003	3.64	WcoilIdot	27a8_27a7	-0.008	27a9_27a8	-0.008	3.621	3.673
tqc02a.Quench.080215121849.836	**87**	9412	20	-0.004	3.70	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	3.528	3.682
tqc02a.Quench.080215135900.793	**88**	9264	20	-0.004	3.61	WcoilIdot	27a8_27a7	-0.009	27a9_27a8	-0.009	4.446	4.446
tqc02a.Quench.080215174143.635	**89**	6879	250	-0.006	2.47	HcoilHcoil	17a3_17a4	-0.006	17a9_17a10	-0.005	4.456	4.453
tqc02a.Quench.080215180535.088	**90**	7216	225	-0.006	2.60	HcoilHcoil	17a9_17a10	-0.007	17a8_17a9	-0.006	4.449	4.448
tqc02a.Quench.080215182115.197	**91**	7230	225	-0.006	2.61	HcoilHcoil	17a9_17a10	-0.007	17a3_17a4	-0.006	4.454	4.457
tqc02a.Quench.080218102810.048	**92**	9080	100	-0.018	4.74	HcoilHcoil	27a9_27a8	-0.012	27a8_27a7	-0.011	4.451	4.453
tqc02a.Quench.080218105837.507	**93**	9196	50	-0.153	16.11	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.448	4.447
tqc02a.Quench.080218180952.177	**94**	6514	**300**	-0.007	2.29	HcoilHcoil	17a3_17a4	-0.007	17a9_17a10	-0.007	4.449	4.446
tqc02a.Quench.080218185730.931	**95**	8747	**200**	-0.424	35.64	HcoilHcoil	27a8_27a7	-0.013	27a9_27a8	-0.013	4.447	4.449
tqc02a.Quench.080220115439.573	**-**	999	0	0.013	0.95	WcoilGnd	V1_TrigFvtB1	-0.001	V1_TrigCvtB1	0.000	4.443	4.441
tqc02a.Quench.080220120553.812	**-**	5391	150	-0.402	13.42	HcoilHcoil	V1_TrigFvtB1	-0.003	V1_TrigCvtB1	-0.003	4.436	4.431
tqc02a.Quench.080221140343.404	**-**	1358	50	0.001	0.11	WcoilGnd	19a10_19b6	-0.002	V1_TrigFvtB1	-0.001	4.445	4.443
tqc02a.Quench.080221141355.280	**-**	1085	0	0.001	0.09	WcoilGnd	V1_TrigFvtB1	-0.001	V1_TrigCvtB1	0.000	4.443	4.444
tqc02a.Quench.080221142203.903	**-**	1129	165	-0.215	0.40	HcoilHcoil	V1_TrigCvtB1	-0.003	V1_TrigFvtB1	-0.003	4.440	4.430
tqc02a.Quench.080221145302.082	**-**	1129	50	0.001	0.10	WcoilIdot	19a10_19b6	-0.003	19a9_19a10	-0.002	4.443	4.435
tqc02a.Quench.080221150353.621	**-**	987	0	-0.577	0.72	HcoilHcoil	V1_TrigCvtB1	-0.003	V1_TrigCvtB2	-0.003	4.441	4.443
tqc02a.Quench.080221152029.144	**-**	972	50	0.001	0.10	WcoilGnd	V1_TrigFvtB1	-0.001	V1_TrigCvtB1	0.000	4.444	4.441

tqc02a.Quench.080221153711.808	**-**	1304	154	0.001	0.12	WcoilGnd	V1_TrigFvtB1	0.000	V1_TrigCvtB2	0.000	4.442	4.433
tqc02a.Quench.080221182943.808	**96**	8925	150	0.000	0.00		------------	----	------------	----	4.500	4.500
tqc02a.Quench.080221192616.674	**97**	8934	149	-0.010	3.87	HcoilHcoil	27a9_27a8	-0.011	27a8_27a7	-0.011	4.443	4.441
tqc02a.Quench.080222081639.733	**98**	7922	207	-0.006	2.96	HcoilHcoil	17a9_17a10	-0.006	17a8_17a9	-0.006	4.444	4.447
tqc02a.Quench.080222083155.933	**99**	6205	250	-0.007	2.13	HcoilHcoil	17a9_17a10	-0.007	17a3_17a4	-0.006	4.447	4.446
tqc02a.Quench.080222085324.940	**100**	5396	300	-0.009	1.75	HcoilHcoil	17bsh2_17bsh1	-0.009	17a9_17a10	-0.008	4.440	4.428
tqc02a.Quench.080222091930.767	**101**	8817	156	-0.011	3.84	HcoilHcoil	27a9_27a8	-0.012	27a8_27a7	-0.012	4.439	4.434
tqc02a.Quench.080222142136.757.	**102**	8807	212	0.000	0.00		------------	----	------------	----	0.000	0.000
tqc02a.Quench.080222144900.368	**103**	7923	212	0.000	0.00		------------	----	------------	----	0.000	0.000
tqc02a.Quench.080222154346.367	**104**	7904	212	-0.006	2.92	HcoilHcoil	17a9_17a10	-0.006	17a8_17a9	-0.006	4.438	4.434
tqc02a.Quench.080222161128.117	**105**	7928	212	-0.007	3.04	HcoilHcoil	17a2_17a3	-0.006	17b3_17b2	-0.006	4.433	4.428
tqc02a.Quench.080222164105.151	**106**	9272	19	-0.007	3.85	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.438	4.427
tqc02a.Quench.080222171633.530	**107**	9266	20	-0.007	3.84	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.433	4.439
tqc02a.Quench.080222174547.092	**108**	9270	19	-0.007	3.84	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.440	4.441
tqc02a.Quench.080222182253.926	**109**	9266	20	-0.006	3.73	HcoilHcoil	27a8_27a7	-0.008	27a9_27a8	-0.008	4.435	4.427

Apparently some magnet training occurred during the ramp rate study at 1.9 K (see two parallel lines for the ramp rates 50-150 A/s in Fig.7) and the quench current increased by ~ 350-400 A. At the end of the test we repeated the 4.5 K ramp rate study and found a much smaller increase in the quench current (~ 50 A).

At 1.9 K the quench current dropped significantly and precipitously at low ramp rates, 5 A/s and 20 A/s, but remained on a plateau at 30 A/s. Similar behavior was observed during the TQC02e magnet test at 1.9 K and could be related to the instability in conductor (TQC02e and TQC02a magnets were built using the same 1-mm Nb_3Sn RRP 54/61 conductor).

Some of the high ramp rate quenches (212 A/s, 250 A/s and 300 A/s) at 4.5 K showed unexpected increases in the quench current due to conditioning ramps. The ramp rate dependence without these pre-conditioned ramps at 4.5 K and with the 1.9 K quenches only after the magnet was trained is shown in Fig.8.

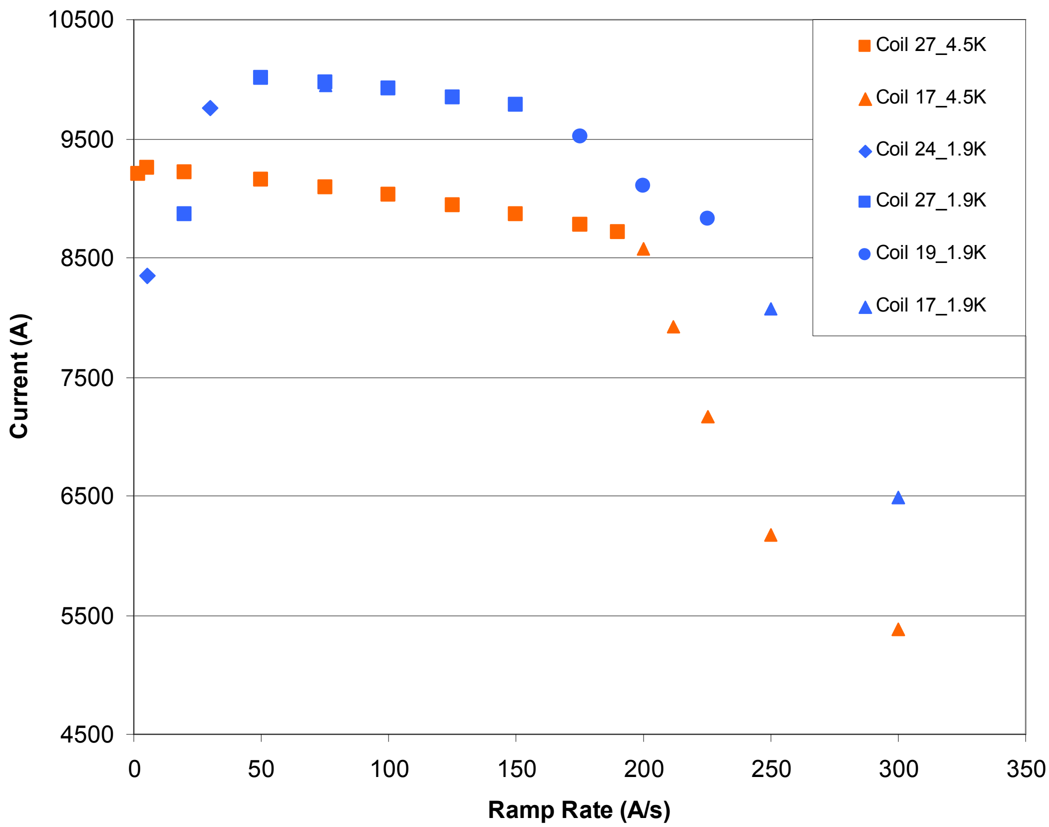

Figure 8. TQC02a ramp rate dependence: pre-conditioned ramps at 4.5 K are removed; 1.9 K quenches are only after the magnet training

5. Temperature Dependence Study

Quench current temperature dependence was studied during the warm-up to 4.5 K after the magnet test at 1.9 K, using two different ramp rates of 20 and 100 A/s. Results are shown in Fig. 9. We see that with the nominal ramp rate of 20 A/s the quench current dropped at temperatures below ~ 3 K. The temperature dependence is smooth for the ramp rate of 100 A/s. This is very suggestive of instability in the Nb_3Sn conductor, which arises due to increased Jc at lower temperature. The ramp rate dependence indicates this instability boundary is very sharp since it does not seem to occur at 30 A/s.

Temperature dependence results for all TQC magnets are summarized in Fig. 10. All quenches during these tests - except for the TQC02a magnet - were performed the nominal at 20 A/s ramp rate. TQC02e and TQC02a magnets showed similar behavior, but the TQC02a magnet exhibited additional degradation.

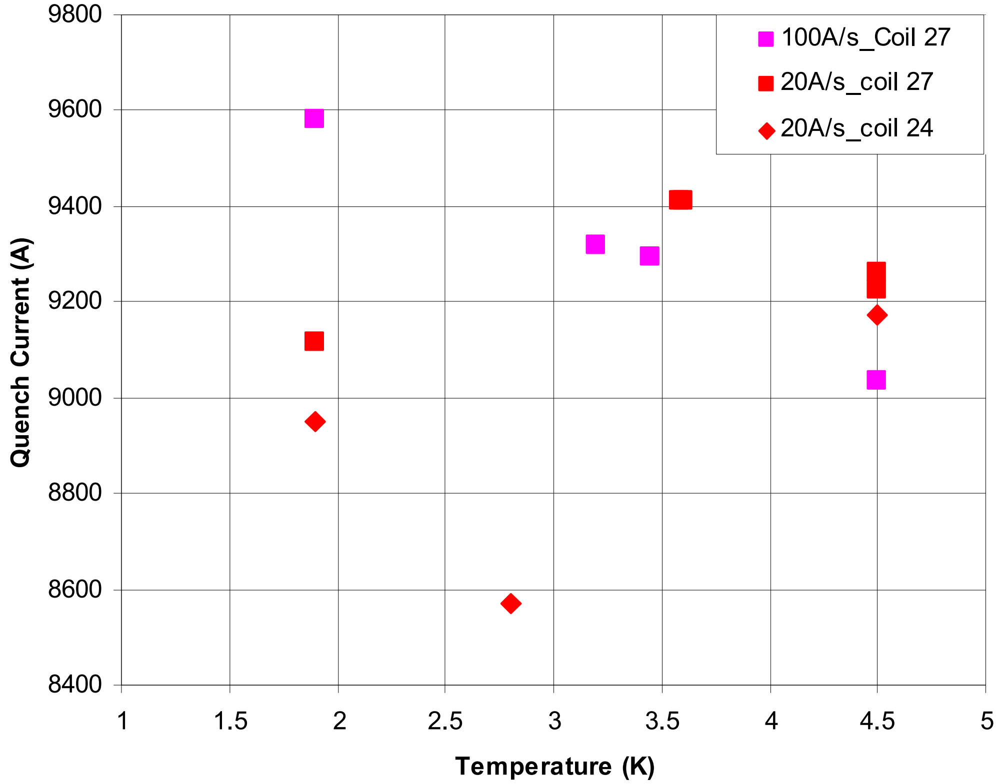

Figure 9. TQC02a temperature dependence

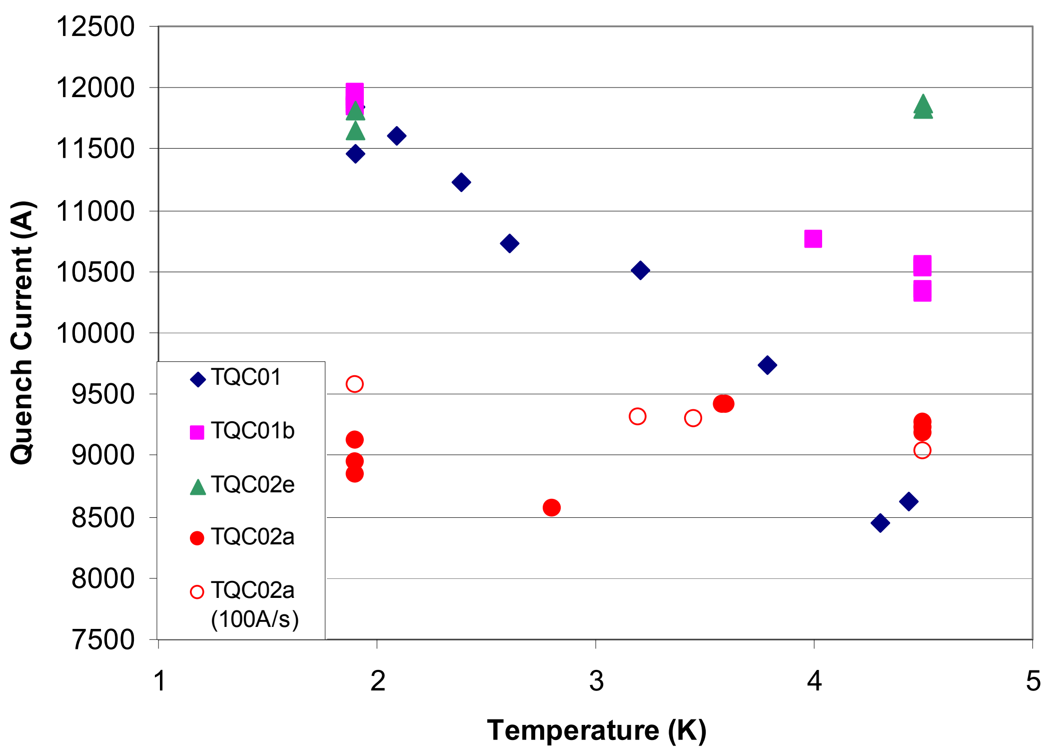

Figure 10. Temperature dependence study for all TQC magnets

6. Measurement of the Residual Resistivity Ratio (RRR)

Estimates of RRR in TQC02a coil segments have been made using data captured during the warm-up after the cold test was completed. The warm-up was started on February 24th and transition from superconducting to normal occurred at 6:25 pm of the same day and data captured at 6:48 pm was used for the cold RRR measurement. Temperature of the magnet at top and bottom were respectively 18.8 K and 17.6 K when the transition occurred.

Coil voltages across “configurable” voltage tap segments were monitored by the *Pentek* data loggers, while a current of alternating polarity, +/- (7-8) ± 0.4 A, was put through the magnet. For both warm (~ 300 K) and cold (~ 18 K) measurements we used the RRR amplifier gains for the voltage tap segments to maximize the signal levels. We had to reduce the RRR gain for all ***a4a5*** segments from 897 to 797 since iso-amplifiers failed to set the requested gain. The probable explanation is that iso-amplifiers failed to set zero-offset for this specific gain value below the hard-coded limits. RRR measurements of the above mentioned ***a4a5*** segments were not affected since this ~ 11% reduction in gain since it was done both for cold and warm measurements.

The magnet reached room temperature and warm voltage measurements were captured on February 28th at ~11:07 am. Data for all segments are shown in Table 3 and the results are graphed in Fig.11. RRR values are reasonably consistent with measurements for other LARP TQC or TQS magnets.

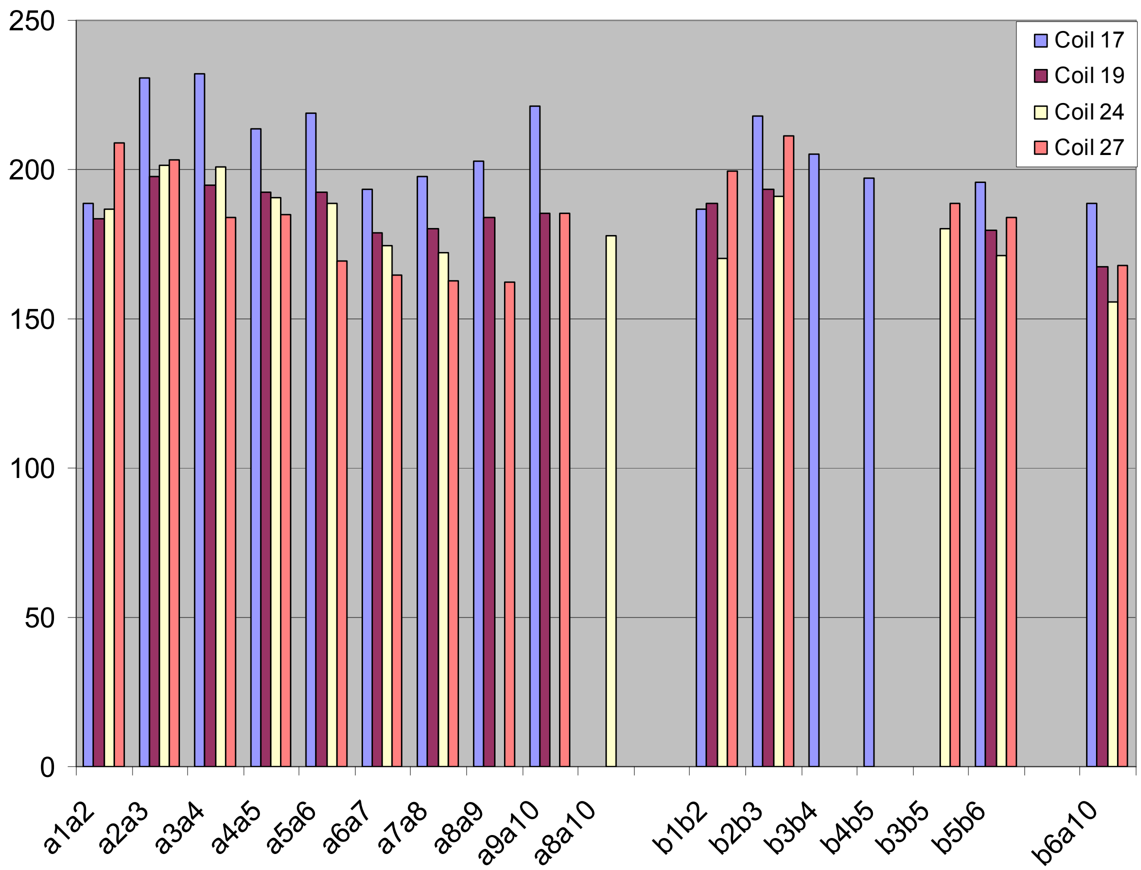

Figure 11. RRR measurements for CVT segments.

Table 3 RRR data for all the CVT segments in TQC02a

	Cold Measurements				Warm Measurements			
Segment	**ΔV(pos.-neg.)**	**ΔI**	**R (cold)**		**ΔV(pos.-neg.)**	**ΔI**	**R (warm)**	**RRR**
V1_VoTap19a1_19a2M_1	0.00003449	16.95	0.0000020		0.00506399	13.57	0.000373	183.4
V1_VoTap19a2_19a3M_1	0.00580373	16.95	0.0003424		0.91760500	13.57	0.067620	197.5
V1_VoTap19a3_19a4M_1	0.00018270	16.95	0.0000108		0.02845730	13.57	0.002097	194.6
V1_VoTap19a4_19a5M_1	0.00045712	16.95	0.0000270		0.07042870	13.57	0.005190	192.4
V1_VoTap19a5_19a6M_1	0.00175269	16.95	0.0001034		0.26990200	13.57	0.019890	192.3
V1_VoTap19a6_19a7M_1	0.00005841	16.95	0.0000034		0.00836866	13.57	0.000617	179.0
V1_VoTap19a7_19a8M_1	0.00017480	16.95	0.0000103		0.02518790	13.57	0.001856	180.0
V1_VoTap19a8_19a9M_1	0.00005710	16.95	0.0000034		0.00840719	13.57	0.000620	183.9
V1_VoTap19a9_19a10M_1	0.00009781	16.95	0.0000058		0.01449710	13.57	0.001068	185.1
V1_VoTap19a10_19b6M_1	0.00011749	16.95	0.0000069		0.01574650	13.57	0.001160	167.4
V1_VoTap19b6_19b5M_1	0.00017890	16.95	0.0000106		0.02668000	13.57	0.001899	179.9
V1_VoTap19b3_19b2M_1	0.00658454	16.95	0.0003885		1.01856000	13.57	0.075060	193.2
V1_VoTap19b2_19b1M_1	0.00003493	16.95	0.0000021		0.00527529	13.57	0.000389	188.6
V1_VoTap17a1_17a2M_1	0.00003273	16.95	0.0000019		0.00494588	13.57	0.000364	188.8
V1_VoTap17a2_17a3M_1	0.00494932	16.95	0.0002920		0.91370500	13.57	0.067333	230.6
V1_VoTap17a3_17a4M_1	0.00015145	16.95	0.0000089		0.02814640	13.57	0.002074	232.1
V1_VoTap17a4_17a5M_1	0.00041132	16.95	0.0000243		0.07038780	13.57	0.005187	213.7
V1_VoTap17a5_17a6M_1	0.00153779	16.95	0.0000907		0.26913500	13.57	0.019833	218.6
V1_VoTap17a6_17a7M_1	0.00005397	16.95	0.0000032		0.00835687	13.57	0.000616	193.4
V1_VoTap17a7_17a8M_1	0.00015901	16.95	0.0000094		0.02515540	13.57	0.001854	197.6
V1_VoTap17a8_17a9M_1	0.00005213	16.95	0.0000031		0.00845425	13.57	0.000623	202.6
V1_VoTap17a9_17a10M_1	0.00008166	16.95	0.0000048		0.01444670	13.57	0.001065	221.0
V1_VoTap17a10_17b6M_1	0.00010360	16.95	0.0000061		0.01564590	13.57	0.001153	188.6
V1_VoTap17b6_17b5M_1	0.00016444	16.95	0.0000097		0.02575750	13.57	0.001898	195.7
V1_VoTap17b5_17b4M_1	0.00003868	16.95	0.0000023		0.00609822	13.57	0.000449	196.9
V1_VoTap17b4_17b3M_1	0.00017049	16.95	0.0000101		0.02797650	13.57	0.002062	205.0
V1_VoTap17b3_17b2M_1	0.00582248	16.95	0.0003435		1.01657000	13.57	0.074913	218.1
V1_VoTap17b2_17b1M_1	0.00003460	16.95	0.0000020		0.00516958	13.57	0.000381	186.6
V1_VoTap27b1_27b2M_1	0.00003125	16.95	0.0000018		0.00499016	13.57	0.000368	199.5
V1_VoTap27b2_27b3M_1	0.00604808	16.95	0.0003568		1.02286000	13.57	0.075377	211.2
V1_VoTap27b3_27b5M_1	0.00022697	16.95	0.0000134		0.03431230	13.57	0.002529	188.8
V1_VoTap27b5_27b6M_1	0.00017447	16.95	0.0000103		0.02571550	13.57	0.001895	184.1
V1_VoTap27b6_27a10M_1	0.00012018	16.95	0.0000071		0.01615790	13.57	0.001191	167.9
V1_VoTap27a10_27a9M_1	0.00009881	16.95	0.0000058		0.01467770	13.57	0.001082	185.5
V1_VoTap27a9_27a8M_1	0.00006597	16.95	0.0000039		0.00857450	13.57	0.000632	162.3
V1_VoTap27a8_27a7M_1	0.00019493	16.95	0.0000115		0.02536640	13.57	0.001869	162.5
V1_VoTap27a7_27a6M_1	0.00006391	16.95	0.0000038		0.00841973	13.57	0.000620	164.6
V1_VoTap27a6_27a5M_1	0.00200795	16.95	0.0001185		0.27242500	13.57	0.020076	169.5
V1_VoTap27a5_27a4M_1	0.00048109	16.95	0.0000284		0.07114520	13.57	0.005243	184.7
V1_VoTap27a4_27a3M_1	0.00019440	16.95	0.0000115		0.02863360	13.57	0.002110	184.0
V1_VoTap27a3_27a2M_1	0.00566692	16.95	0.0003343		0.92230500	13.57	0.067966	203.3
V1_VoTap27a2_27a1M_1	0.00002868	16.95	0.0000017		0.00479949	13.57	0.000354	209.1
V1_VoTap24b1_24b2M_1	0.00003762	16.95	0.0000022		0.00512474	13.57	0.000378	170.1
V1_VoTap24b2_24b3M_1	0.00660042	16.95	0.0003894		1.01043000	13.57	0.074461	191.2
V1_VoTap24b3_24b5M_1	0.00023573	16.95	0.0000139		0.03400510	13.57	0.002506	180.2
V1_VoTap24b5_24b6M_1	0.00018764	16.95	0.0000111		0.02570730	13.57	0.001894	171.1
V1_VoTap24b6_24a10M_1	0.00012030	16.95	0.0000071		0.01501110	13.57	0.001106	155.9

V1_VoTap24a10_24a9M_1	0.00015629	16.95	0.0000092	0.02224910	13.57	0.001640	177.8
V1_VoTap24a8_24a7M_1	0.00017935	16.95	0.0000106	0.02471320	13.57	0.001821	172.1
V1_VoTap24a7_24a6M_1	0.00006059	16.95	0.0000036	0.00846889	13.57	0.000624	174.6
V1_VoTap24a6_24a5M_1	0.00175614	16.95	0.0001036	0.26522300	13.57	0.019545	188.6
V1_VoTap24a5_24a4M_1	0.00045274	16.95	0.0000267	0.06900950	13.57	0.005085	190.4
V1_VoTap24a4_24a3M_1	0.00017202	16.95	0.0000101	0.02769180	13.57	0.002041	201.1
V1_VoTap24a3_24a2M_1	0.00564880	16.95	0.0003333	0.91037400	13.57	0.067087	201.3
V1_VoTap24a2_24a1M_1	0.00003299	16.95	0.0000019	0.00492818	13.57	0.000363	186.6

7. Quench Locations

Time-of-flight based quench-origins were calculated from resistive signal growth in voltage tap segments for several quenches during the TQC02a magnet training, using the following three times: quench-onset, 1st exit and 2nd exit (when available). The time-of-flight distance assumed the known voltage-tap locations and equal quench-propagation speeds for both quench-fronts. In our estimations we use the voltage tap locations and segment length shown in Table 6. Voltage tap locations and the CVT segments were already shown in Section 2.

All training quenches developed in coils 24 and 27 only and in the inner layer of the coils. High ramp rate quenches were located in the mid-plane segments and are not considered in this study.

Estimated quench locations in coil 24 at 1.9 K and 4.5 K temperatures are shown in Fig.19 (figure is shown looking at the inside surface of the coil). Quenches in coil 27 are shown in Fig.20. We see quenches mostly are located at the return end of the coils, near to junctions between the pole pieces and very near voltage tap ***A8***. There is no evidence for anomalously low RRR in any of the quenching sections.

Table 6 TQC02a configurable voltage tap locations and calculated segment lengths z = 0 mm for the *A10* voltage tap

Vtap (ID)	**Y (mm)**	**Z (mm)**	**Segment**	**L.calc (mm)**
A6	-11.08	-230.04	A3A4	564
A7	9.08	-230.04	A6A7	168
A8	9.08	314.58	A7A8	545
A9	-9.08	314.58	A8A9	184
A10	-9.08	0.00	A9A10	315
B6	26.51	-230.00	A10B6	352
B5	26.51	326.58	B6B5	557
B4	-26.51	326.58	B5B4	135
B3	-26.51	-230.00	B4B3	557

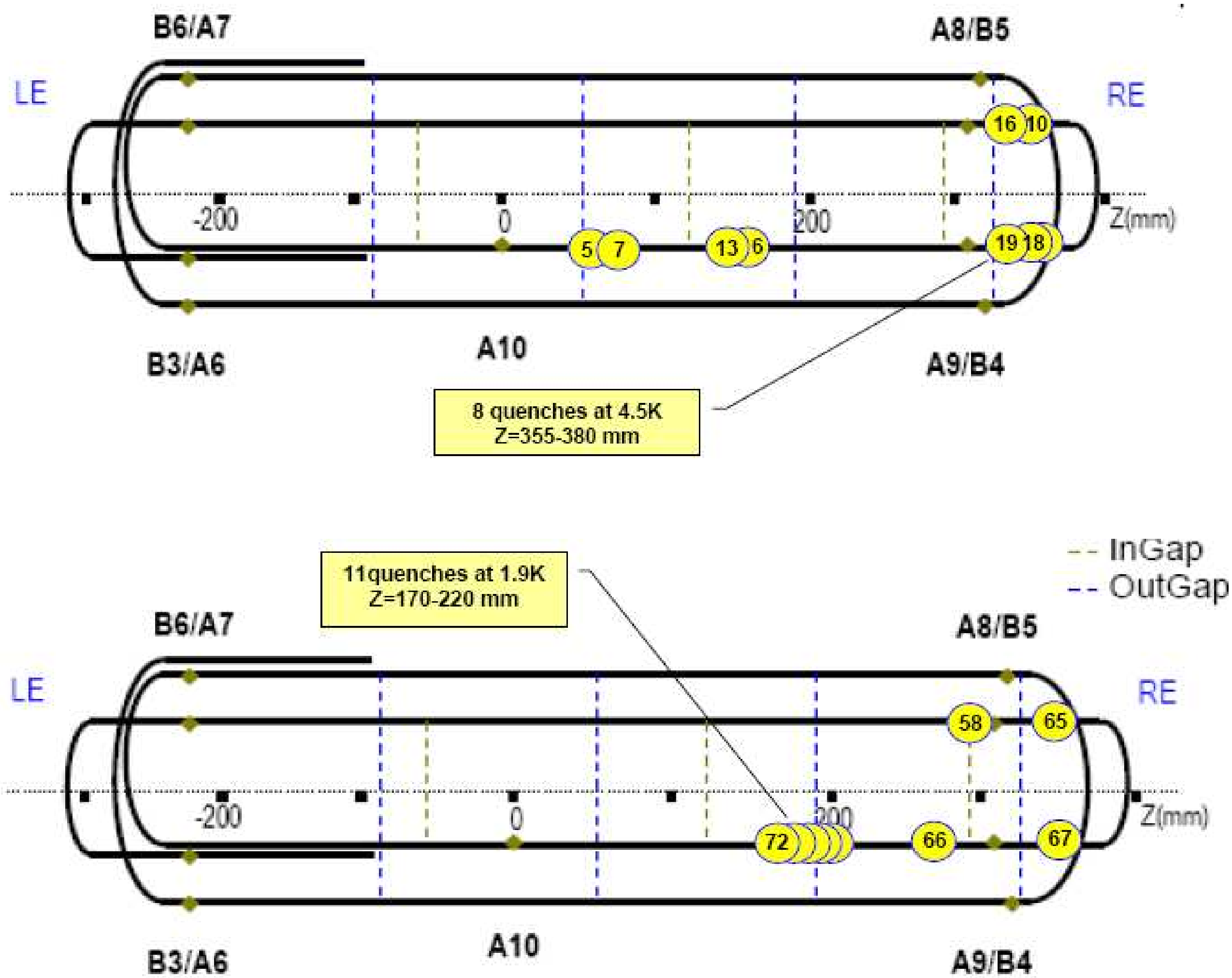

Figure 19. Quench locations in coil 24 for the quenches at 4.5 K (top) and 1.9 K (bottom)

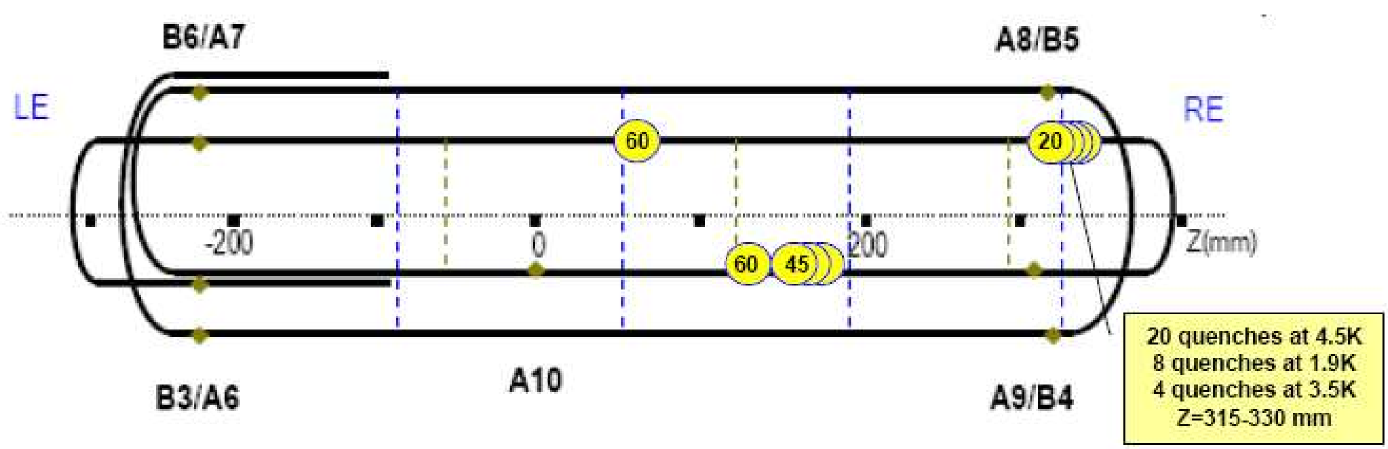

Figure 20. Quench locations in coil 27 at both 4.5 K and 1.9 K

8. Magnetic Measurements

Field quality magnetic measurements were made with the VMTF vertical drive system and DSP rotating harmonic coil readout cart. Several data sets were captured: warm z-scan before cool down, z-scans at 4.5 K and 1.9 K. The full cold measurement program is described below. A 10 cm long tangential probe, with 2 dipole, 2 quadrupole and 1 tangential windings, was utilized. This probe was specially built for LARP magnet measurements with a radius of 2.17 cm, optimized to the warm finger inner diameter.

The positive direction of the z-axis for the scans is pointing from the magnet center to the lead end, from which the probe was inserted. Each measurement (e.g., at one z-position) contains data from at least 25 full rotations of the probe, and z-scans steps were equal to the length of the probe.

The cold magnetic measurement program at 4.5 K and 1.9 K consisted of the following measurements:

a. Z-scans (4.5 K) at 6.5 kA and 8 kA,
b. Z-scans at 12.3 Tm/m (LHC injection, estimated to be 0.720 kA), 100 Tm/m (estimated to be 5.8 kA),
c. Eddy current loops with the ramp rates 20 A/s, 40 A/s and 80 A/s up to 8.0 kA with the probe positioned in the center of the magnet,
d. Dynamic effects measurement, which included a current accelerator profile, similar to the one used in LHC MQXB quads (15 min. duration of the injection plateau and the probe positioned in the center of the magnet).

Also special measurements of quad center stability over time were performed at fixed current.

All magnetic measurement results are presented at 22.5 mm reference radius, the official radius adopted for LHC.

Table 4 summarizes the geometrical harmonics at 45 T/m field gradient for the TQC and TQS magnets. Not allowed harmonics of several units are observed almost in all magnets.

Table 4 TQC and TQS harmonics at 45 T/m field gradient

n	TQC				TQS		
	calc	measured			calc	measured	
		01	02E	02A		01	02
b_3	0.00	2.01	1.07	-3.42	0.00	-1.46	2.98
b_4	0.00	-1.9	-2.92	1.98	0.00	-0.52	1.31
b_5	0.00	0.58	-2.11	2.15	0.00	3.06	-1.45
b_6	0.90	1.71	2.72	0.71	5.00	5.4	6.23
b_7	0.00	0.07	-0.37	0.14	0.00	0.07	0.05
b_8	0.00	0.01	0.12	0.19	0.00	-0.11	-0.13
b_9	0.00	0.04	0.08	0.00	0.00	0.02	0.1
b_{10}	0.00	-0.06	-0.02	-0.06	-0.04	0.02	-0.05
a_3	0.00	-1.72	1.17	-4.38	0.00	4.41	0.66
a_4	0.00	0.62	1.47	-0.68	0.00	-1.99	0.82
a_5	0.00	-1.33	-3.31	-0.55	0.00	0.71	-1.5
a_6	0.00	-0.1	0.59	-1.64	0.00	-0.37	0.12
a_7	0.00	0.1	-0.09	0.05	0.00	-0.11	-0.01
a_8	0.00	-0.03	-0.19	-0.10	0.00	-0.18	-0.1
a_9	0.00	0.08	0.11	-0.11	0.00	-0.02	0.02
a_{10}	0.00	0	-0.08	0.04	0.00	0	-0.08

Table 5 TQC02a body and average harmonics at different currents

	Average Injection	Average 8 kA	body only Injection	body only 8 kA
b_3	1.73	-2.97	-0.85	-5.62
b_4	-5.37	-1.23	-7.16	-2.64
b_5	-50.09	-1.78	-52.85	-2.37
b_6	-45.79	-2.00	-48.01	-2.94
b_7	-0.66	0.29	-1.01	0.03
b_8	-0.12	0.03	-0.15	-0.11
b_9	1.18	-0.31	1.65	-0.22
b_10	1.08	-0.18	1.38	-0.13
a_3	-3.53	2.97	-5.2	1.94
a_4	-35.58	-2.79	-36.9	-2.53
a_5	-45.26	-4.01	-45.4	-3.06
a_6	-0.73	-0.07	-1.00	-0.44
a_7	1.01	-0.09	1.40	-0.01
a_8	1.80	-0.58	2.55	-0.28
a_9	1.42	-0.39	1.87	-0.19
a_10	0.02	-0.01	-0.01	0.02

Table 5 summarizes the harmonics at injection (0.72 kA) and maximum measured current (8 kA), averaged over the magnet (left) and for the center body position (right). In general, the field harmonics are on the order of several units. The b_5 and b_6 at injection are observed to be relatively large, ~ 50 units at reference radius 22.5 cm, similar to 10 units in TQS01c at reference radius of 17 mm.

Fig.12 shows the transfer function (TF) versus z coordinate profiles at 0.72, 5.8 and 8.0 kA. The effective length of the magnet is calculated to be 0.742 m, 0.746 m and 0.747 m at these currents.

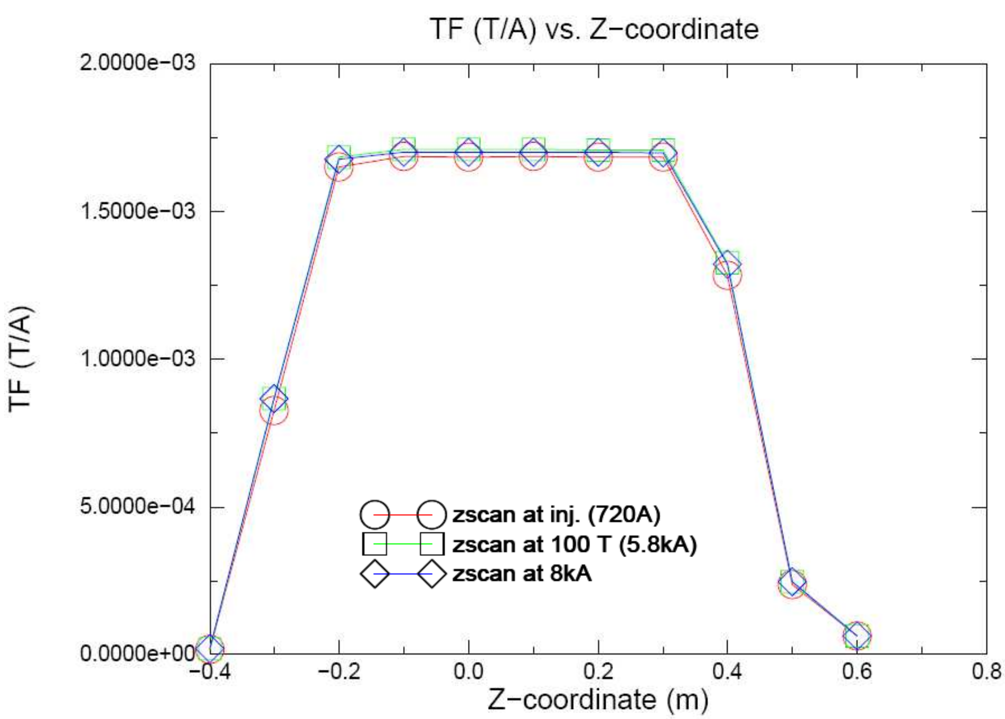

Figure 12. The magnet TF vs z-coordinate at 0.72 kA, 5.8 kA and 8 kA

Fig.13 shows the dodecapole versus time. The current profile used in this measurement was derived from the profile of production inner triplet LHC quadrupole (LQXB) measurements. The duration of the injection porch was set to 15 min at 12.8 T, accordingly to the LHC specifications. One can observe that the b6 *decay* and *snapback*, which are commonly observed in NbTi magnets, are not present (see the time interval from ~700 to ~1700 s).

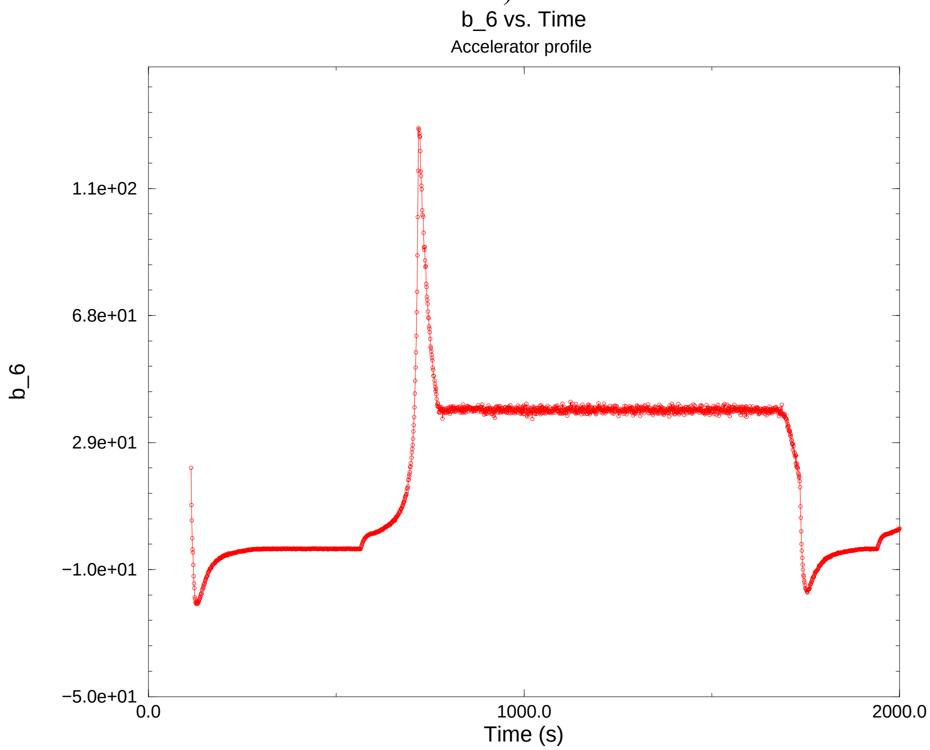

Figure 13. Dodecapole (b6, in units) vs time (s) in a modified LHC accelerator current profile

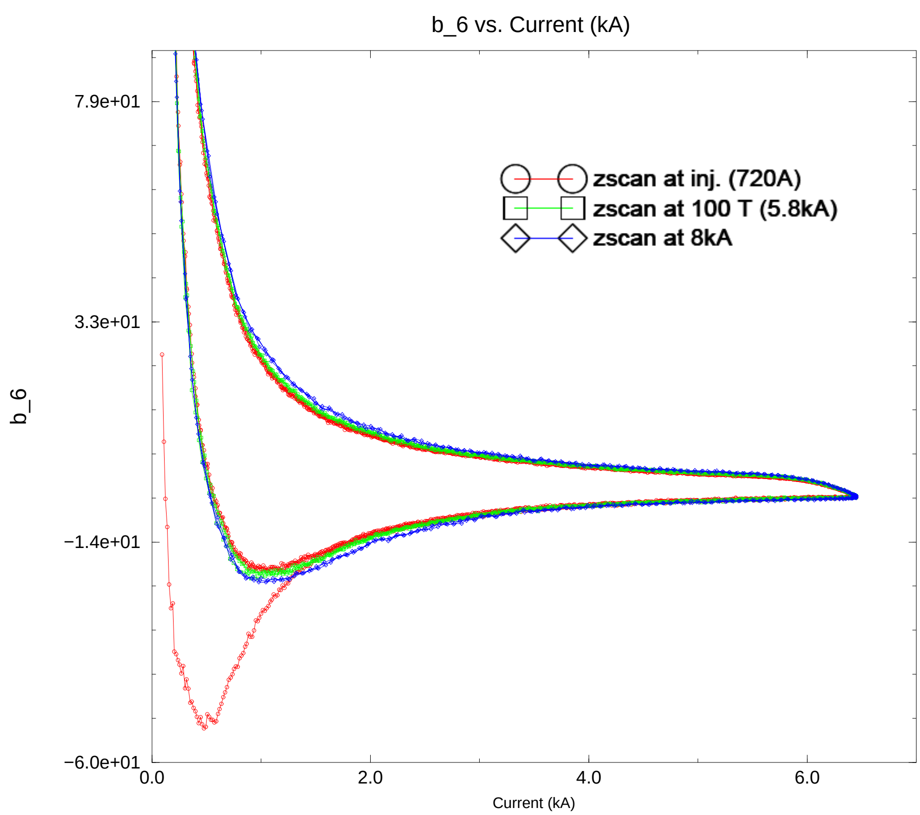

Figure 14. Dodecapole (b6) vs excitation current at different ramp rates

Current loops at 20, 40 and 80 A/s for TQC02a quadrupole have been executed. The b_6 difference between the ramp rate loops is small, indicating small or negligible eddy current effect on the hysteresis loop, similar to what was observed in TQS01c measurements. The b_6 hysteresis loops are shown in Fig.14.

Ramp rate dependence of the TF at different field gradients is shown in Fig.15. Different interstrand resistance in coils may explain this dependence.

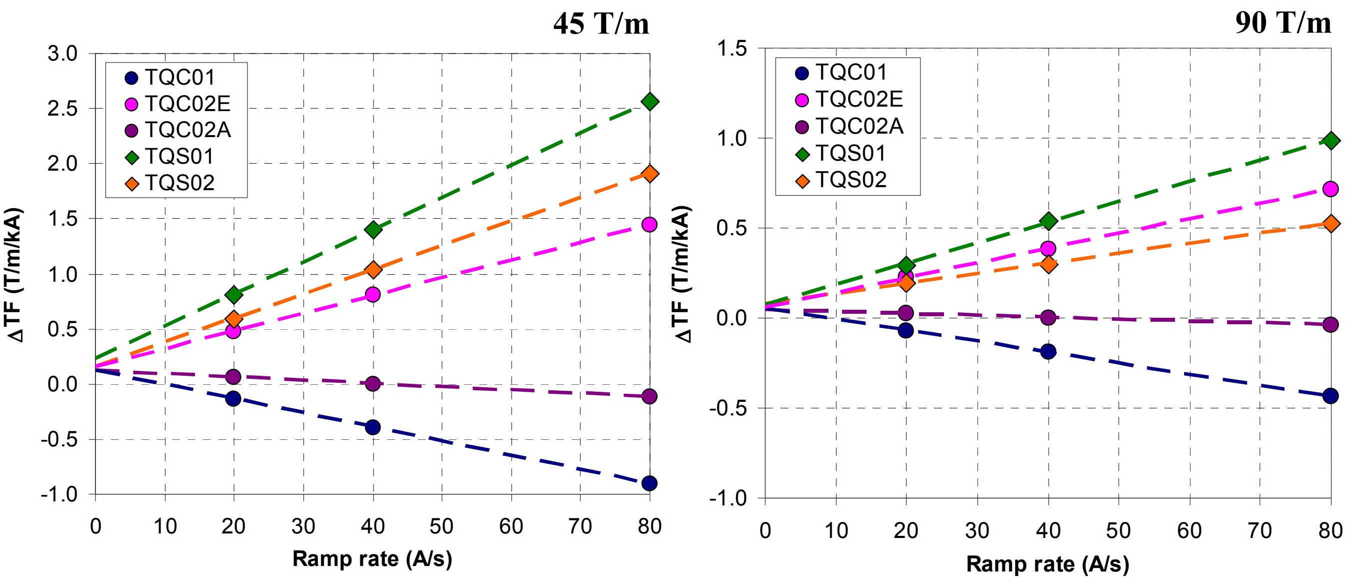

Figure 15. TF ramp rate dependence at 45 T/m and 90 T/m field gradients

The underlying harmonics due to coil geometry are obtained by extrapolating loop widths to 0 A/s ramp rate at fixed current, or gradient. These are summarized in Table 6 at 45 T/m field gradient for the various TQ magnets that we have measured.

Table 6 Loop width at 45 T/m extrapolated to 0 A/s

n	TQC01		TQC02E		TQC02A		TQS01		TQS02	
	Δa_n	Δb_n	Δa_n	Δb_n	Δa_n	Δb_n	Δa_n	Δb_n	Δa_n	Δb_n
3	-0.36	2.04	1.48	2.16	-2.85	-0.05	1.54	0.07	-3.79	2.16
4	2.50	-3.65	7.61	-6.67	-10.12	-0.17	2.70	1.23	13.39	0.06
5	-12.66	-4.62	-23.32	-13.52	-14.77	14.96	2.97	7.77	-2.23	-8.22
6	-0.25	14.19	0.13	17.89	-0.13	13.67	-0.23	13.45	0.40	15.97
7	0.06	-0.11	0.81	-0.54	0.53	0.49	0.36	-0.24	0.27	0.10
8	-0.30	0.15	-0.90	0.08	0.76	-0.01	-0.05	-0.13	0.92	0.31
9	0.24	0.16	0.71	0.31	0.45	-0.42	-0.03	-0.19	0.15	-0.10
10	0.03	-0.17	-0.25	-0.53	0.01	-0.36	-0.05	-0.33	0.01	-0.22

9. Energy Loss Measurements

Energy loss measurements were made as a function of ramp rate to study AC losses from eddy currents and iron/conductor magnetization. One of the goals of these measurements also was commissioning the new measurement system using the PXI modules and the *Labview* based software. The reference and more comprehensive measurements were done using the existing system utilizing VME modules in the *VxWorks* real-time operating system to communicate with a 3458 DVM. Therefore, in the text or figures we refer to the “old” measurement system as a *VxWorks* system and to the new system as a *Labview* system.

The energy loss measurements were performed on February 15th and 18th at 4.5 K temperature. Sawtooth ramps from 500 A to 6500 A were used to measure energy losses as a function of ramp rate in the range 75-225 A/s (in 25 A/s steps). 5 measurements were taken for each ramp rate. Results and the linear fit to the data obtained with the *VxWorks* system are shown in Fig.16. The fit intercept, corresponding to the hysteresis energy loss, is ~ 2.15 kJ. The fit slope, measuring losses from eddy currents, is 4.07 J/A/s.

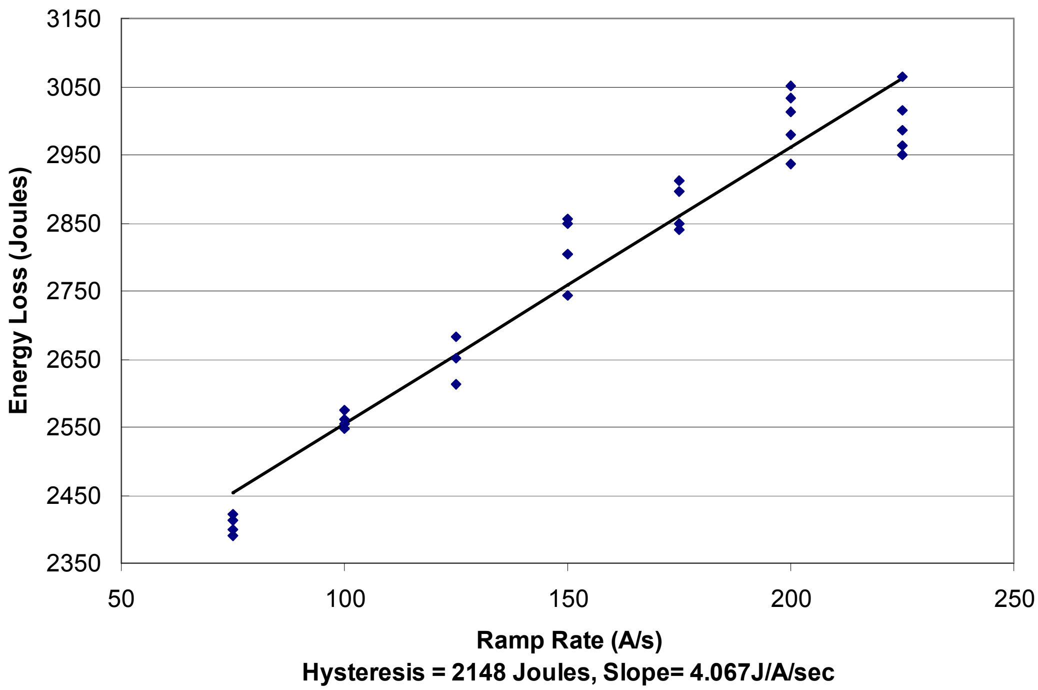

Figure 16. Energy loss measurements at 4.5 K using the *VxWorks* system

For the first time in high field magnet testing, energy losses were also measured in the individual coils using the *VxWorks* system in order to check if the results are consistent with each other, and to study whether they could explain why the high ramp rate quenches occurred in coils 17 and 19. These measurements were performed at 75 A/s, 150 A/s and 200 A/s ramp rates (see Fig.17); the slope and intercept of the linear fit to the each coil data are listed below:

Coil #:	**17**	**19**	**24**	**27**
Slope	0.713	1.564	1.312	1.273
Intercept	536.35	463.03	438.53	560.71

Combining the individual coil measurements, the summed intercept and slope are 2.0 kJ and 4.86 J/A/s respectively. These numbers are in good agreement with the whole coil measurements for the same 75 A/s, 150 A/s and 200 A/s ramp rates: 2.1 kJ and 4.66 J/A/s.

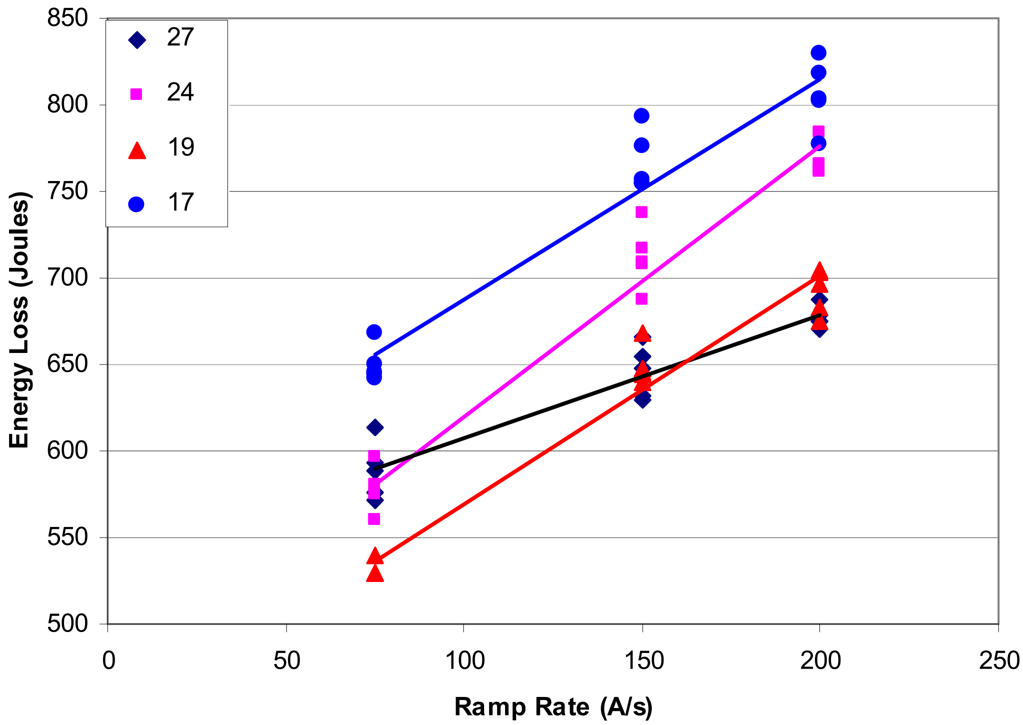

Figure17. Energy Loss measurements in the individual coils at 4.5 K using the *VxWorks* system

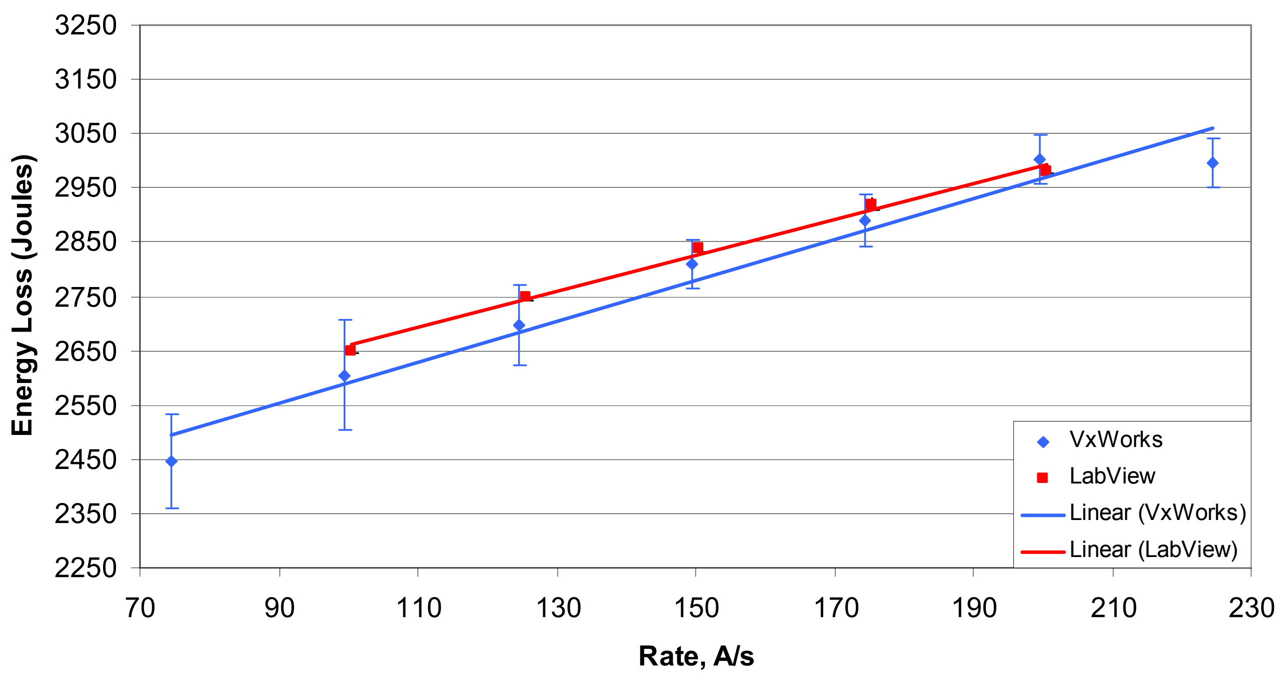

Figure 18. Energy loss measurements with the *VxWorks* and the *Labview* systems

Comparison of results from the measurements made with the use of the *VxWorks* and the *Labview* systems is shown in Fig.18. The results are reasonably consistent, although it is not fully understood why the *Labview*-measured errors are so small. The new *Labview* system commissioning is not completed yet.

10. Conclusion

TQC02a magnet is a 1-m long quadrupole fabricated as a part of the LARP program at Fermilab. The coils of this magnet were made of 1-mm Nb_3Sn strands based on the "Restack Rod Process" (RRP) of 54/61 sub-element design. Two coils of this magnet were new (24 and 27) and two coils previously were collared but never tested (17 and 19).

Cable for the TQC02a coils was made using 3 different billets: 8647 (reel 940, in coils 17 and 19), 8781 (reel 946, in coil 24) and 8857 (reel 947, in coil 27). Previously, TQC02e and TQS02a magnets were built using similar conductor, but these magnets showed better quench performance. TQC02a exhibited larger degradation in new coils and reached a plateau ~30 % below the predicted SSL.

TQC02a magnet, as well as TQC02e and TQS02a magnets, exhibited erratic low ramp rate quench performance at 1.9 K, with noticeable improvement at higher ramp rates (30 A/s – 150 A/s). Conductor instability is a strong candidate to explain the magnet temperature dependence and ramp rate behavior. Quench locations in TQC02a are concentrated at the return end, near the junction between the pole pieces, which also may indicate some mechanical damage during the assembly process.

For the first time in high field magnet testing, energy losses were measured in the individual coils and good correlation was found between measured eddy current losses and observed quenches at high ramp rates in coil 17.

11. Disassembly and Inspection

Following the cold test, TQC02a was systematically disassembled to look for any anomalies that might explain the unexpected low performance. The procedure followed and results obtained will be reported in a separate note.