TS-SSC 91-257
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Summary of DSA326 Quenches

DSA326 is the fourth Fermilab 50 mm aperture short SSC dipole magnet. This magnet experienced three thermal cycles during which it was quenched (spontaneous quenches) a total of 54 times. Tests during the first cooldown included quench training at temperatures of 4.3 K and 4.2 K. During the second and third cooldown the magnet was quenched at temperatures of 4.3 K, 4.2 K and 3.8 K. The first and second cooldown tests also included ramping down of magnet from 6500 A at high rates (up to 400 A/S) , strain gage runs to >7300 A at 4.3 K and harmonics measurements as a function of current at the center of the magnet and as a function of position at 5000 A. Some additional tests performed during the second cooldown included ramp rate dependence study of quench current at 4.3 K. Heater induced quench studies were done during the first thermal cycle. Throughout the magnet test the bore tube was evacuated except during magnetic measurement tests. The zero current end preload during the first two cooldowns was on the order of 250 lbs./bullet and it was increased to 4000 lbs./bullet (at ambient temperature) for the third cycle of tests. There was no obvious change in quench performance due to the increased end preload. The measured magnet temperatures used in this report are the average of three thermometers used on the magnet and the temperature fluctuation is within .05K unless otherwise. This report is a chronological summary of test results followed by a comparison of magnet performance and predicted quench currents at different temperatures.

Quench History (First Cooldown)

A summary of all the quench files with quench locations is attached at the end of this report and the quench history is plotted in Figure 1. Figure 2 is a map of voltage tap locations used to determine the quench origins. The quench propagation velocity in straight sections of the coil was typically ≥ 80 m/s and ~33 m/s in ramp splices during a standard plateau quench. The first spontaneous quench occurred during a strain gage run (Iq=7343 A) at 4.3 K, located in ramp splice side straight section of the upper inner turn 19 about 3.3 ms (26 cm ± 5 cm) from the ramp-splice voltage tap.

The second quench was in the pole turn at a current of ~7362 A. The magnet achieved an average plateau current of ~7386 A during the first cooldown. The magnet was quenched four times (4.3K) at plateau current before going on to a strain gage run and then to quench study at 4.2K. All standard plateau quenches (SPQ) were at a ramp rate of 16 A/s and 4.3 K. All quenches originated in the straight section of the upper inner pole turn. Four quenches were on ramp-splice side and one was on the non ramp-splice side of the coil. The quench location was about 38 ±5 cm from the lead tap (i.e. ramp splice tap). The quench velocity of these quenches was ~83 m/s. Figure 3 shows the voltages in three earliest segments for a typical quench. Figure 4 shows the location of a typical quench on the ramp splice and non-ramp splice side of the coil. Figure 5 shows the voltage growth in three earliest segments due to a typical quench on the side opposite the ramp-splice. The location of such quenches is ~33cm ±2 cm from the lead tap . The quench currents have a standard deviation of ~28 A and the full range of quench currents is almost 70 A. See Table 1 for details.

4.2 K Quenches

The magnet did not show any training at 4.2 K and reached a current of 7671 A in the first quench. All 4.2 K quenches were in turn 19 of upper inner coil in the same location (pole turn) as 4.3 K quenches. Three quenches were in the straight section of the non ramp splice side of the coil and one was in the ramp splice side of the coil. The magnet was ramped at a nominal ramp rate of 16 A/s and an average quench current of ~7666 A was achieved. All quenches in turn 19 were about 4 -5ms from the lead voltage tap and had a $V_q \approx 83$ m/s. One quench on ramp splice side of the magnet was ~7 ms (58 ± 5 cm) from the ramp splice voltage tap. The quench currents have a standard deviation of ~14 A and the full range of quench currents is 25 A. See Table 1 for details. The magnet temperature was not lowered any further during the first thermal cycle.

Quench History (Second Cooldown)

During the second cooldown period there are some indications of magnet training at some points at both 4.3 K and 4.2 K. The quench current at each temperature was some what erratic and the large spread in quench currents at 16 A/s cannot be explained by temperature fluctuations. The location of all the 16 A/s quenches, at 4.3 K and 4.2 K, was similar to the quenches in the first test cycle. The full range of quench currents is much higher for the second test cycle which is not fully understood. There is no evident low ramp rate plateau during the second cycle of cold tests. BNL magnet DSA309 also showed an erratic quench plateau until a ramp rate of 2 A/s was tried.

4.3K Quenches

During second cooldown the magnet was quenched 19 times at 4.3K. Ramp rate studies was also done during the second cooldown. All 16 A/s quenches were in the upper inner pole turn. The first spontaneous quench occured during a strain gage ramp (16 A/s, 4.35K) at 7465 A. The second quench was at a lower current of 7333 A (4.29K), which can not be explained with temperature fluctuations, still in the pole turn of the upper inner coil. The magnet quenched twice close to ~7460 A and once at 7441 A. The quench current on five quenches was similar to first cooldown quenches at about 7400 A and the remaining two quenches of 16 A/s were close to 7420 A. T he wide range of quench currents at 16 A/s is quite evident during the second cooldown.

4.2 K Quenches

It was then quenched 10 times at 4.2K. Once again all 16 A/s quenches occured in upper inner coil either on the ramp splice or non ramp splice side of the coil. The temperature fluctuation from quench to quench was ~.06K. The first quench was at 7460 A similar to quenches in first test cycle. Following three quenches were near 7500 A and the fifth quench was at a much higher current of 7661 A. The sevencth quench was (7568 A) almost 100 A lower than the previous two quenches. The magnet quenched four times close to 7660 A and once at 7612 A. As mentioned above the magnet had a wide range of quench currents at 16 A/s. The magnet temperature was then lowered to 3.8 K.

Ramp Rate Studies

Ramp rate dependence of DSA326 was studied during the second cooldown at 4.3K. The magnet was quenched at a series of ramp rates ranging from the nominal rate of 16 A/s to 300 A/s. The only 6 A/s quench in the second cooldown was at 7421 A in the upper inner pole turn. All high ramp rate quenches in second test cycle, from 25 - 300 A/s, were in the upper inner multiple turn rather than in one of the ramp splices. All of these quenches originated near the lead end tap of the upper inner coil in turn 13 (on the ramp splice side of the coil). Since the multiple turns are not very well instrumented, its rather difficult to pin point the exact location of these quenches. Figure 6 compares the ramp rate dependence of DSA326 with other 50 mm aperture magnets. All the quenches during third test cycle were at 16 A/s.

Quench History (Third Cooldown)

The magnet was recooled the third time. It was then quenched six times at 4.3K. The location of all 16 A/s quenches was similar to the quenches in previous two coolodowns, i.e; pole turn of upper inner coil. The temperature fluctuation from quench to quench was ~.05K. At 4.3K the quench currents have a standard deviation of ~22 and the full range of quench currents is almost 54 A at 16 A/s. The only quench at 4.2K during third cooldown was at 7656 A. The magnet temperature was then lowered to 3.8 K.

Low Temperature Studies

DSA326 temperature was lowered to 3.8 K during the second and third cooldowns. During the second test cycle it was quenched five times at 3.8K. All the quenches were in the upper inner pole turn. The first quench was at 7930 A about 2 ms (~17 cm) from the ramp splice voltage tap. Then the magnet was quenched four times and it reached a plateau current of ~8126 A. These quenches were ~4 ms from the ramp splice voltage tap in the straight section of the upper inner coil turn 19, with a quench velocity $V_q \approx$ 83 m/s. A strain gage run was also taken during low temperature studies. At lower temperature the plateau quench currents had a standard deviation of 7 A and the spread in plateau quench currents was also very small (15 A).

During the third cooldown the magnet was quenched three times at 3.8K and it exhibited no retraining. All quenches were standard plateau quenches. It reached an average quench current of 8105 A with a standard deviation of ~14 A. Table 1 shows this and the average temperature during each test cycle.

As discussed in TS-SSC 90-26, the SSC dipole magnets should be able to ramp down at the initial ramp rate of -325 A/s. To show magnet's stability DSA326 was ramped down from 6500 A to 4000 A at high ramp rates of -100, -200 , -300 and -400 A/s without quenching. At the end of this cycle the magnet was ramped at 16 A/s to quench. This test was performed during the first and second test cycles.

During the first two cooldowns the zero current end preload, at ambient temperature, was ~1.11 kN (~250 lbs.) per bullet (~30 in-lb torque/bullet). For third cooldown, the magnet end preload was increased to ~18 kN (~4000 lbs.) per bullet and the lead end screws were also torqued to ~37 ft-lb/screw. There is no evident difference in quench currents due to increased end preload.

Temperature Dependence

The quench performance of a magnet depends on temperature of helium bath in which the magnet is immersed. The relation between quench current for dI/dt ≤ 16 A/s and the average of the three thermometers placed at top, middle and bottom of the magnet is shown in Figure 7. The solid line in the figure is the critical current as predicted by Chris Quigg's program using Mike Green's parametrization of the critical surface. Table 1 shows the averages of quench currents at 16 A/s at different temperatures (the average of three thermometers placed on the magnet skin). A plateau quench for this magnet is the one which originates in the pole turn of upper inner coil (turn 19) and is near the maximum current for a given temperature.

The cable used to wind the inner coils of DSA326 are from reel SSC 3S-00021. The short sample critical current (Ic) at 7 Tesla, 4.22 K for this cable is 10,079 A. A comparison of magnet performance and predicted quench current based on the short sample data is given in Table 2 and Table 1 shows the measured quench current at different temperatures during three cooldowns. The I_q for frst four quenches, at 4.2K during the second cooldown, was close to 7500 A, and the rest six quenches were at much higher currents. There are two average quench currents for second cooldown at 4.2 K. Quenches 2 thru 4 have been bunched toghether and quenches 5 thru 10 have been grouped together in table 1.

Table 1: Measured quench current at different temperatures during four test cycles.

Test Cycle #	Temperature	Measured Iquench	Full Range of current
1	4.34 K	7386 ± 11A	
3	4.36 K	7404 ± 9 A	
1	4.17 K	7666 ± 9 A	
2	4.22 K	7518 A	34 A (for quench 2 thru quench 4, test cycle #2)
2	4.19 K	7642 A	108 A (for quench 5 thru quench 10,test cycle #2)
3	4.18 K	7656 A	
2	3.80 K	8126 ±4 A	
3	3.82 K	8105 ±9A	

Table 2: Predicted critical current at different temperatures

Temp (K)	Predicted Iquench
4.35	7310 A
4.22	7470 A
3.80 K	7960 A

The error bars on the measured data are the standard deviation (of quench currents) divided by the square root of the number of quenches for each temperature for each thermal cycle.

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Quench File Summary
DSA326

Q#	File	I-m	Idot	I-t	Idot	QDC	MIITs	t-Q	V-max	Coil	t(H)	V(H)	T(t)	T(m)	T(b)	P	LL	Location
First Cooldown:																		
	0	-75.	0.	0.0	0.0	V-dI	0.0	0.000	0.	UO	0.000	0.	0.00	0.00	0.00	0.	0.	manual trip to check s.c.
	1	-85.	0.	0.0	0.0	Vtot	0.0	-.002	7.	UO	0.000	0.	4.23	4.18	4.18	744.	73.	manual trip to check s.c.
	2	-3674.	0.	0.0	0.0	Cu L	0.0	0.000	0.	UO	0.000	0.	4.23	4.18	4.18	743.	73.	manual trip to check s.c.
	3	-3865.	0.	0.0	0.0	Cu L	0.0	0.000	0.	UI	0.000	0.	4.23	4.18	4.18	743.	73.	manual trip to check s.c.
	4	-4114.	0.	0.0	0.0	Cu L	0.0	0.000	0.	UI	0.000	0.	4.23	4.18	4.18	743.	73.	manual trip to check s.c.
	5	1002.	0.	0.0	0.0	V-dI	0.0	0.000	-6.	UI	0.000	0.	4.23	4.18	4.18	743.	72.	manual trip to check s.c.
	6	1991.	0.	0.0	0.0	U-L	0.0	0.000	-11.	UI	0.000	0.	4.35	4.30	4.30	834.	75.	manual trip to check s.c.
	7	1002.	0.	0.0	0.0	V-dI	0.0	0.000	-6.	UI	0.000	0.	4.36	4.32	4.31	845.	72.	manual trip to check s.c.
	8	997.	0.	0.0	0.0	Vtot	0.0	-.003	-6.	UI	0.000	0.	4.40	4.35	4.35	874.	85.	manual trip to check s.c.
-------------4.3 K QUENCHES-----------																		
1	9	7343.	16.	0.0	0.0	U-L	0.0	-.017	-25.	UI	0.000	0.	4.39	4.34	4.33	867.	74.	IU19SR 3.5 ms from Ramp Splice
2	10	7362.	16.	0.0	0.0	U-L	0.0	-.014	-23.	UI	0.000	0.	4.35	4.30	4.29	853.	65.	IU19SR 3.5 ms from Ramp Splice
3	11	7397.	16.	0.0	0.0	U-L	0.0	-.011	-25.	UI	0.000	0.	4.40	4.35	4.34	871.	69.	IU19SR 3.5 ms from Ramp Splice
4	12	7392.	16.	0.0	0.0	U-L	0.0	-.015	-25.	UI	0.000	0.	4.38	4.33	4.32	867.	66.	IU19SR 3.5 ms from Ramp Spl
5	13	7416.	16.	0.0	0.0	U-L	0.0	-.010	-25.	UI	0.000	0.	4.35	4.30	4.29	866.	66.	IU19SR 2.5 ms from Ramp Spl
6	14	7406.	16.	0.0	0.0	U-L	0.0	-.009	-24.	UI	0.000	0.	4.37	4.32	4.31	878.	67.	IU19SL 4 ms from LE
-----------4.2 KStudies-----------																		
	15	1007.	0.	0.0	0.0	Vtot	0.0	0.000	-6.	UI	0.000	0.	4.20	4.15	4.15	724.	76.	Manual Trip to check system
7	16	7671.	16.	0.0	0.0	U-L	0.0	-.006	-24.	UI	0.000	0.	4.20	4.15	4.15	724.	76.	IU19SL ~4 ms from LE
8	17	7671.	16.	0.0	0.0	U-L	0.0	-.012	-24.	UI	0.000	0.	4.20	4.15	4.15	724.	59.	IU19SR ~7 ms from Ramp Spl
9	18	7676.	16.	0.0	0.0	U-L	0.0	-.008	-24.	UI	0.000	0.	4.20	4.15	4.15	724.	59.	IU19SL ~4.8 ms from LE
--------Heater tests----------																		
	19	-6.	0.	0.0	0.0	V-dI	0.0	0.000	0.	UO	0.000	0.	4.20	4.15	4.15	724.	84.	
	20	-2.	0.	0.0	0.0	V-dI	0.0	0.000	0.	UO	0.000	0.	4.20	4.15	4.15	724.	84.	
	21	-2.	0.	0.0	0.0	V-dI	0.0	0.000	0.	UO	0.000	0.	4.20	4.15	4.15	723.	75.	
	22	-2.	0.	0.0	0.0	U-L	0.0	0.000	0.	UO	0.000	0.	4.20	4.15	4.15	723.	74.	
	23	1991.	0.	0.0	0.0	V-dI	0.0	-.325	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	24	1991.	0.	0.0	0.0	V-dI	0.0	-.341	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	73.	
	25	2025.	0.	0.0	0.0	V-dI	0.0	-.285	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	73.	
	26	1986.	0.	0.0	0.0	V-dI	0.0	-.535	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	73.	
	27	1986.	0.	0.0	0.0	V-dI	0.0	-.492	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	28	1986.	0.	0.0	0.0	V-dI	0.0	-.352	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	29	1991.	0.	0.0	0.0	V-dI	0.0	-.347	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	30	1986.	0.	0.0	0.0	V-dI	0.0	-.346	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	31	1991.	0.	0.0	0.0	V-dI	0.0	-.352	-12.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	32	4978.	0.	0.0	0.0	V-dI	0.0	-.028	-30.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	33	4978.	0.	0.0	0.0	V-dI	0.0	-.012	-30.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	34	4978.	0.	0.0	0.0	V-dI	0.0	-.035	-30.	UI	0.000	0.	4.20	4.15	4.15	723.	74.	
	35	4978.	0.	0.0	0.0	V-dI	0.0	-.032	-30.	UI	0.000	0.	4.26	4.22	4.21	771.	48.	
	36	62.	100.	0.0	0.0	Vtot	0.0	-.002	7.	UO	0.000	0.	4.20	4.16	4.15	724.	74.	
	37	1986.	0.	0.0	0.0	V-dI	0.0	-.554	-12.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	
	38	1986.	0.	0.0	0.0	V-dI	0.0	-.554	-12.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	
	39	1986.	0.	0.0	0.0	V-dI	0.0	-.503	-12.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	
	40	1986.	0.	0.0	0.0	V-dI	0.0	-.515	-12.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	
	41	1986.	0.	0.0	0.0	V-dI	0.0	-.518	-12.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	
	42	4973.	0.	0.0	0.0	V-dI	0.0	-.050	-30.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	
	43	4978.	0.	0.0	0.0	V-dI	0.0	-.045	-30.	UI	0.000	0.	4.21	4.17	4.16	730.	75.	
	44	4968.	0.	0.0	0.0	V-dI	0.0	-.051	-30.	UI	0.000	0.	4.21	4.17	4.16	730.	75.	
	45	4978.	0.	0.0	0.0	V-dI	0.0	-.049	-30.	UI	0.000	0.	4.21	4.17	4.16	730.	75.	
	46	4978.	0.	0.0	0.0	V-dI	0.0	-.050	-30.	UI	0.000	0.	4.21	4.17	4.16	730.	75.	
	47	4978.	0.	0.0	0.0	V-dI	0.0	-.049	-30.	UI	0.000	0.	4.21	4.17	4.16	730.	75.	
	48	-2.	0.	0.0	0.0	V-dI	0.0	0.000	1.	LO	0.000	0.	0.00	0.00	0.00	0.	0.	
	49	1986.	0.	0.0	0.0	V-dI	0.0	0.000	-12.	UI	0.000	0.	4.21	4.17	4.16	730.	75.	

	50	1986.	0.	0.0	0.0	V-dI	0.0	-.454	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	51	1986.	0.	0.0	0.0	V-dI	0.0	0.000	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	52	1986.	0.	0.0	0.0	V-dI	0.0	0.000	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	53	4973.	0.	0.0	0.0	V-dI	0.0	-.019	-30.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	54	4978.	0.	0.0	0.0	V-dI	0.0	-.019	-30.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	55	4973.	0.	0.0	0.0	V-dI	0.0	-.004	-30.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	56	4973.	0.	0.0	0.0	V-dI	0.0	-.006	-31.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	57	4978.	0.	0.0	0.0	V-dI	0.0	-.007	-31.	UI	0.000	0.	4.20	4.16	4.15	725.	76.	
	58	4978.	0.	0.0	0.0	V-dI	0.0	-.002	-30.	UI	0.000	0.	4.23	4.19	4.19	750.	73.	
	59	1991.	0.	0.0	0.0	V-dI	0.0	-.520	-12.	UI	0.000	0.	4.23	4.19	4.19	750.	73.	
	60	1991.	0.	0.0	0.0	V-dI	0.0	-.519	-12.	UI	0.000	0.	4.23	4.19	4.19	750.	73.	
	61	1986.	0.	0.0	0.0	V-dI	0.0	-.521	-12.	UI	0.000	0.	4.23	4.19	4.19	750.	73.	
	62	4973.	0.	0.0	0.0	V-dI	0.0	-.044	-30.	UI	0.000	0.	4.23	4.19	4.19	750.	73.	
	63	4973.	0.	0.0	0.0	V-dI	0.0	-.045	-30.	UI	0.000	0.	4.22	4.18	4.18	741.	75.	
	64	4978.	0.	0.0	0.0	V-dI	0.0	-.046	-30.	UI	0.000	0.	4.22	4.18	4.18	741.	75.	
	65	1986.	0.	0.0	0.0	V-dI	0.0	-.245	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	66	1986.	0.	0.0	0.0	V-dI	0.0	-.050	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	67	1986.	0.	0.0	0.0	V-dI	0.0	-.023	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	68	1991.	0.	0.0	0.0	V-dI	0.0	-.023	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	69	1986.	0.	0.0	0.0	V-dI	0.0	-.019	-12.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	70	4978.	0.	0.0	0.0	V-dI	0.0	-.007	-31.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	71	4973.	0.	0.0	0.0	V-dI	0.0	-.009	-31.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
	72	4983.	0.	0.0	0.0	V-dI	0.0	-.005	-31.	UI	0.000	0.	4.20	4.16	4.15	725.	77.	
10	73	7646.	16.	0.0	0.0	U-L	0.0	-.006	-24.	UI	0.000	0.	4.20	4.16	4.15	724.	74.	IU19SL 4.5 ms from LE v tap

Second Cooldown:

--------------4.3 K QUENCHES-----------

	74	997.	0.	0.0	0.0	V-dI	0.0	0.000	-6.	UI	0.000	0.	4.41	4.36	4.36	877.	73.	manual trip to check safety ckt
11	75	7465.	16.	0.0	0.0	U-L	0.0	-.011	-27.	UI	0.000	0.	4.39	4.33	4.33	855.	83.	IU19SR ~3.5 ms from Ramp Splice
12	76	7333.	16.	0.0	0.0	U-L	0.0	-.008	-22.	UI	0.000	0.	4.33	4.27	4.26	859.	87.	IU19SL ~3.2 ms from LE tap
13	77	7426.	16.	0.0	0.0	U-L	0.0	-.008	-21.	UI	0.000	0.	4.26	4.20	4.20	850.	77.	IU19SL ~3 ms from LE tap
14	78	7406.	16.	0.0	0.0	U-L	0.0	-.012	-26.	UI	0.000	0.	4.36	4.31	4.29	840.	58.	IU19SR ~3.5 ms from Ramp Spl
15	79	7392.	16.	0.0	0.0	U-L	0.0	-.010	-24.	UI	0.000	0.	4.38	4.33	4.32	858.	70.	IU19SR ~4.2 ms from Ramp Spl
16	80	7397.	16.	0.0	0.0	U-L	0.0	-.010	-25.	UI	0.000	0.	4.39	4.32	4.32	857.	76.	IU19SL ~3.8 ms from LE tap
17	81	7460.	16.	0.0	0.0	U-L	0.0	-.011	-26.	UI	0.000	0.	4.41	4.36	4.35	906.	77.	IU19SR ~3.5 ms from Ramp Spl
18	82	7402.	16.	0.0	0.0	U-L	0.0	-.010	-25.	UI	0.000	0.	4.39	4.33	4.33	855.	68.	IU19SL ~2.5 ms from LE tap
19	83	7441.	16.	0.0	0.0	U-L	0.0	-.011	-26.	UI	0.000	0.	4.40	4.35	4.34	911.	56.	IU19SR ~3 ms from Ramp Spl
20	84	7397.	16.	0.0	0.0	U-L	0.0	-.011	-26.	UI	0.000	0.	4.39	4.34	4.34	860.	74.	IU19SR ~3 ms from Ramp Spl

----------Ramp Rate Studies---------

21	85	7421.	6.	0.0	0.0	U-L	0.0	-.011	-27.	UI	0.000	0.	4.37	4.31	4.30	870.	73.	IU19SR ~3 ms from Ramp Spl
22	86	7421.	16.	0.0	0.0	U-L	0.0	-.011	-25.	UI	0.000	0.	4.38	4.32	4.31	878.	78.	IU19SR ~3 ms from Ramp Spl
23	87	7372.	25.	0.0	0.0	U-L	0.0	-.007	19.	UI	0.000	0.	4.40	4.34	4.33	867.	72.	IU multiturn tap 327
24	88	7328.	50.	0.0	0.0	U-L	0.0	-.006	21.	UI	0.000	0.	4.36	4.31	4.31	835.	80.	IU multiturn tap 327
25	89	7044.	100.	0.0	0.0	U-L	0.0	-.007	-21.	UI	0.000	0.	4.36	4.31	4.30	850.	70.	IU multiturn tap 327
26	90	6936.	150.	0.0	0.0	U-L	0.0	-.007	-22.	UI	0.000	0.	4.38	4.33	4.32	867.	80.	IU multiturn tap 327
27	91	6770.	200.	0.0	0.0	U-L	0.0	-.007	-23.	UI	0.000	0.	4.37	4.32	4.31	846.	71.	IU multiturn tap 327
28	92	6594.	300.	0.0	0.0	U-L	0.0	-.013	-25.	UI	0.000	0.	4.38	4.32	4.31	850.	71.	IU multiturn tap 327
29	93	6687.	250.	0.0	0.0	U-L	0.0	-.007	-24.	UI	0.000	0.	4.37	4.31	4.31	851.	72.	IU multiturn tap 327

----------4.2 K QUENCHES-----------

30	94	7460.	16.	0.0	0.0	U-L	0.0	-.008	-22.	UI	0.000	0.	4.23	4.19	4.18	781.	75.	IU19SL ~3 ms from LE tap
31	95	7519.	16.	0.0	0.0	U-L	0.0	-.011	-23.	UI	0.000	0.	4.27	4.23	4.20	774.	66.	IU19SL ~3 ms from LE tap
32	96	7500.	16.	0.0	0.0	U-L	0.0	-.009	-23.	UI	0.000	0.	4.27	4.22	4.21	773.	73.	IU19SL ~3.8 ms from LE tap
33	97	7534.	16.	0.0	0.0	U-L	0.0	-.011	-24.	UI	0.000	0.	4.27	4.22	4.22	770.	69.	IU19SR ~6.5 ms from Ramp Spl
34	98	7661.	16.	0.0	0.0	U-L	0.0	-.007	-23.	UI	0.000	0.	4.20	4.15	4.15	720.	73.	IU19SL ~4 ms from LE tap
35	99	7676.	16.	0.0	0.0	U-L	0.0	-.007	-23.	UI	0.000	0.	4.21	4.16	4.15	727.	80.	IU19SL ~4 ms from LE tap
36	100	7568.	16.	0.0	0.0	U-L	0.0	-.010	-23.	UI	0.000	0.	4.24	4.19	4.19	750.	84.	IU19SL ~5.7 ms from LE tap
37	101	7671.	16.	0.0	0.0	U-L	0.0	-.011	-24.	UI	0.000	0.	4.20	4.15	4.15	718.	77.	IU19SR ~6.5 ms from Ramp Spl
38	102	7661.	16.	0.0	0.0	U-L	0.0	-.008	-23.	UI	0.000	0.	4.20	4.16	4.15	722.	73.	IU19SL ~4.5 ms from LE tap
39	103	7612.	16.	0.0	0.0	U-L	0.0	-.006	-24.	UI	0.000	0.	4.26	4.21	4.20	766.	77.	IU19SL ~2.8 ms from LE tap

------------3.8 K QUENCHES-----------

Q#	File	I-m	Idot	I-t	Idot	QDC	MIITs	t-Q	V-max	Coil	t(H)	V(H)	T(t)	T(m)	T(b)	P	LL	Location
40	104	7930.	16.	0.0	0.0	U-L	0.0	-.013	-23.	UI	0.000	0.	3.84	3.80	3.80	497.	92.	IU19SR ~2 ms from Ramp Spl
41	105	8121.	16.	0.0	0.0	U-L	0.0	-.005	-22.	UI	0.000	0.	3.83	3.79	3.80	496.	82.	IU19SR ~4 ms from Ramp Spl
42	106	8136.	16.	0.0	0.0	U-L	0.0	-.005	-22.	UI	0.000	0.	3.82	3.78	3.78	492.	70.	IU19SR ~3.5 ms from Ramp Spl
43	107	8121.	16.	0.0	0.0	U-L	0.0	-.007	-22.	UI	0.000	0.	3.85	3.81	3.80	505.	70.	IU19SR ~4 ms from Ramp Spl
44	108	8126.	16.	0.0	0.0	U-L	0.0	-.005	-23.	UI	0.000	0.	3.79	3.75	3.76	479.	70.	IU19SR ~4 ms from Ramp Spl

Third Cooldown:

-------------4.3 K QUENCHES----------

Q#	File	I-m	Idot	I-t	Idot	QDC	MIITs	t-Q	V-max	Coil	t(H)	V(H)	T(t)	T(m)	T(b)	P	LL	Location
	109	1002.	0.	0.0	0.0	V-dI	0.0	0.000	-6.	UI	0.000	0.	4.39	4.34	4.34	858.	76.	manual trip to check safety ckts
	110	1002.	0.	0.0	0.0	V-dI	0.0	0.000	-6.	UI	0.000	0.	4.37	4.32	4.32	844.	74.	manual trip to check safety ckts
45	111	7441.	16.	0.0	0.0	U-L	0.0	-.012	-32.	UI	0.000	0.	4.42	4.36	4.36	878.	74.	IU19SR ~4 ms from Ramp Spl
46	112	7387.	16.	0.0	0.0	U-L	0.0	-.010	-27.	UI	0.000	0.	4.41	4.36	4.36	877.	58.	IU19SL ~3.5 ms from LE tap
47	113	7421.	16.	0.0	0.0	U-L	0.0	-.010	-25.	UI	0.000	0.	4.40	4.34	4.34	861.	76.	IU19SR ~5.2 ms from Ramp Spl
48	114	7392.	16.	0.0	0.0	U-L	0.0	-.012	-26.	UI	0.000	0.	4.40	4.35	4.34	871.	79.	IU19SR ~6 ms from Ramp Spl
49	115	7397.	16.	0.0	0.0	U-L	0.0	-.010	-27.	UI	0.000	0.	4.37	4.32	4.31	847.	67.	IU19SR ~5.5 ms from Ramp Spl
50	116	7387.	16.	0.0	0.0	U-L	0.0	-.011	-27.	UI	0.000	0.	4.39	4.33	4.32	855.	70.	IU19SR ~5.5 ms from Ramp Spl
51	117	7656.	16.	0.0	0.0	U-L	0.0	-.010	-24.	UI	0.000	0.	4.21	4.16	4.16	726.	73.	IU19SR ~2.5 ms from Ramp Spl

-------------- 3.8 K Studies--------------

Q#	File	I-m	Idot	I-t	Idot	QDC	MIITs	t-Q	V-max	Coil	t(H)	V(H)	T(t)	T(m)	T(b)	P	LL	Location
52	118	8092.	16.	0.0	0.0	U-L	0.0	-.005	-22.	UI	0.000	0.	3.84	3.80	3.80	499.	87.	IU19SR ~4.2 ms from Ramp Spl
53	119	8121.	16.	0.0	0.0	U-L	0.0	-.006	-22.	UI	0.000	0.	3.85	3.81	3.81	505.	88.	IU19SR ~4.5 ms from Ramp Spl
54	120	8102.	16.	0.0	0.0	U-L	0.0	-.005	-22.	UI	0.000	0.	3.84	3.81	3.80	503.	81.	IU19SR ~3.5 ms from Ramp Spl
	121	5355.	0.	0.0	0.0	Cu L	0.0	-.001	0.	LI	0.000	0.	3.84	3.80	3.79	503.	94.	

FORMAT:

Q#	File	I-m	Idot	I-t	Idot	QDC	MIITs	t-Q	V-max	Coil	t(H)	V(H)	T(t)	T(m)	T(b)	P	LL	Location
A5,	I5,	F8.0,	F5.0,	F5.1,	F5.1,	A5,	F5.1,	F6.3,	F6.0,	A4,	F6.3,	F5.0,	F5.2,	F5.2,	F5.2,	F5.0,	F5.0,	2X,A30

NOTATION KEY

Q#	Quench number or Spot heater number (e.g. s4 is spot heater 4)
File	Quench file number
I-m	Main coil current at quench
Idot	Main coil dI/dt at quench
I-t	Trim coil current at quench
Idot	Trim coil dI/dt at quench
QDC	Name of quench detection circuit which tripped:
	1) U-L Upper - Lower Coil
	2) V-dI Magnet - Idot
	3) SC L SC Pwr Leads - Idot
	4) Vtot Magnet
	5) Trim Trim Coil
	6) Cu L Cu Pwr Leads - IR
	7) GndI Ground Fault Monitor
	8) Thru Through Bus - Idot
MIITs	Integral of (I**2)dt from t-Q to "infinity"
t-Q	Time first voltage appears in V(Upper) - V(Lower) (relative to quench detection time)
V-max	Maximum voltage across any quarter coil
Coil	Coil corresponding to V-max
t(H)	Protection heater firing time (relative to quench detection time); -.999 if heater did not fire
V(H)	Protection heater firing voltage; -999. if heater did not fire
T(t)	Temperature at top of magnet
T(m)	Temperature at middle of magnet
T(b)	Temperature at bottom of magnet
P	Dewar pressure (Torr)
LL	Liquid level (%)
Location	Quench or spot heater location

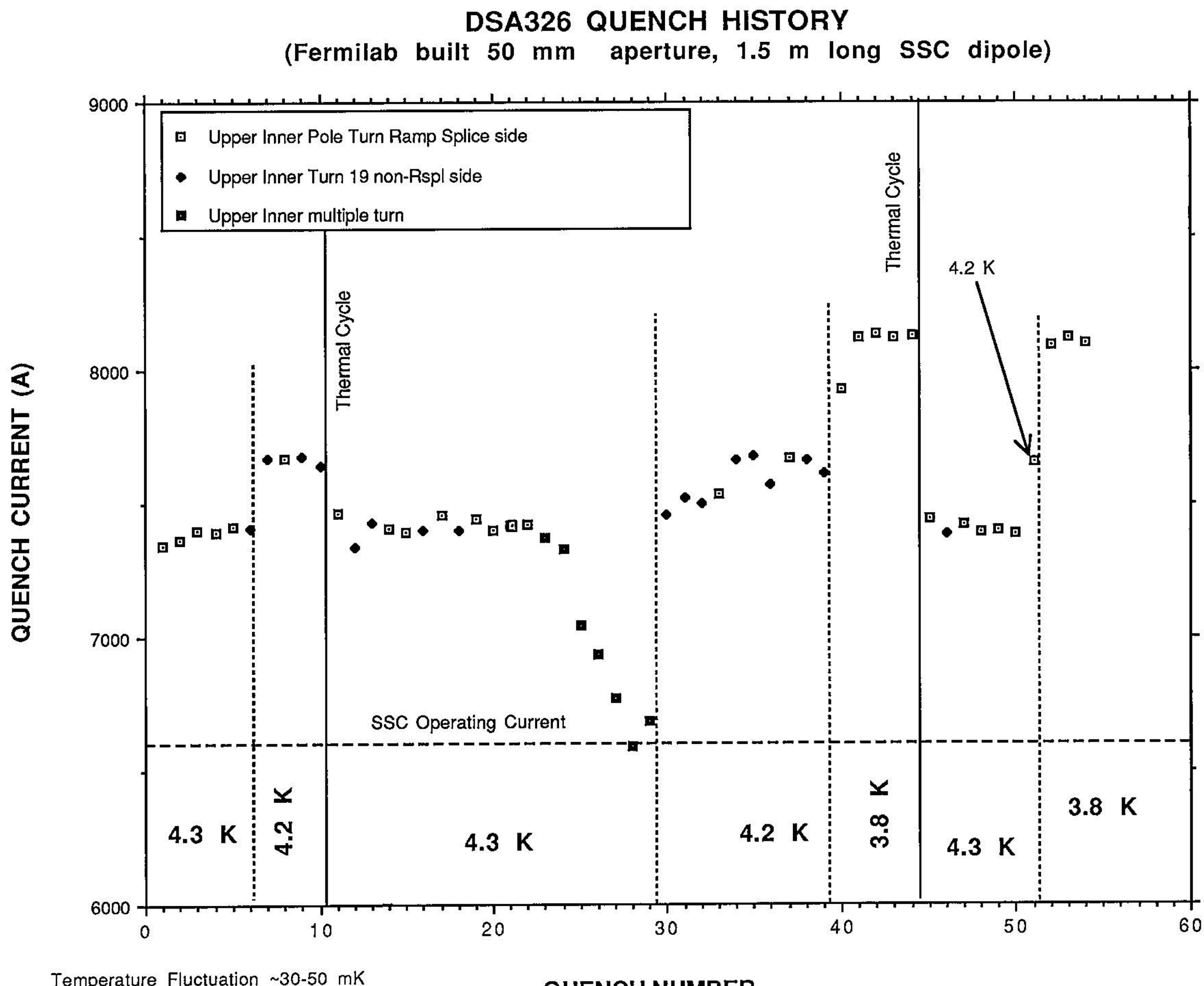
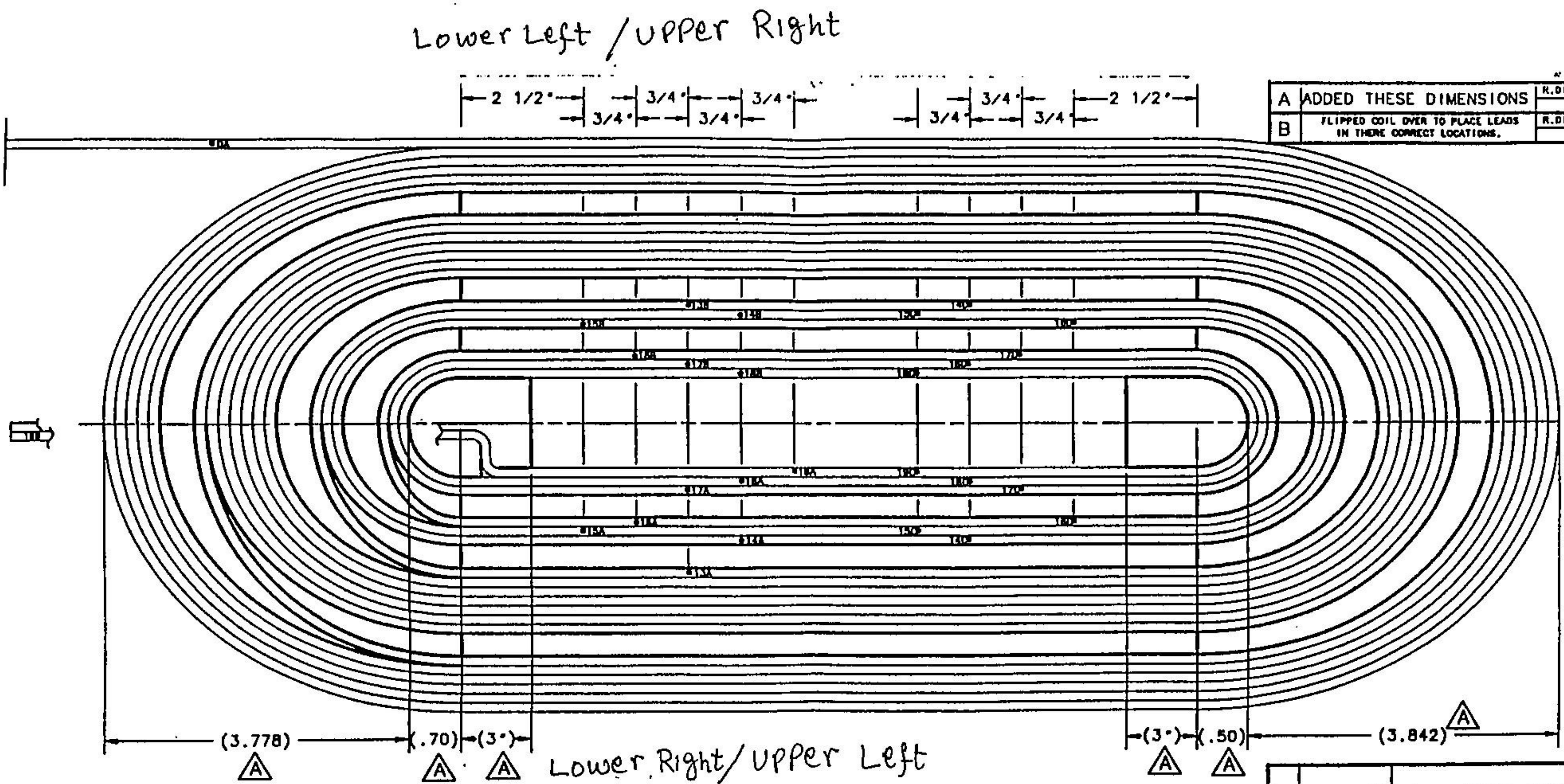

DSA326 QUENCH HISTORY
(Fermilab built 50 mm aperture, 1.5 m long SSC dipole)
Upper Inner Pole Turn Ramp Splice side
Upper Inner Turn 19 non-Rspl side
Upper Inner multiple turn
QUENCH CURRENT (A)
9000
8000
7000
6000
Thermal Cycle
Thermal Cycle
4.2 K
SSC Operating Current
4.3 K
4.2 K
4.3 K
4.2 K
3.8 K
4.3 K
3.8 K
0
10
20
30
40
50
60
Temperature Fluctuation ~30-50 mK
QUENCH NUMBER

Figure 1



A	ADDED THESE DIMENSIONS	R.DIXON	11/16/90
B	FLIPPED COIL OVER TO PLACE LEADS IN THERE CORRECT LOCATIONS.	R.DIXON	12/06/90

Figure 2

NOTE:

1. VOLTAGE TAP WIRES FOR TAPS 0A, 19B, AND THE HALF COIL TAP ARE #22 AWG TEFLON INSULATED.
2. THE REMAINING VOLTAGE TAP WIRES ARE #32 AWG TEFLON INSULATED.
3. TAP WIRES WITH THE SAME NUMBER AT EACH END SHOULD FORM A TWISTED PAIR (A-B AND C-D).
4. VOLTAGE TAP WIRE SHOULD FOLLOW THE CABLE TO WHICH THEY ARE SOLDERED UNTIL THEY MEET AND ARE TWISTED WITH THEIR "MATE".
5. COIL AS VIEWED FROM INSIDE.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

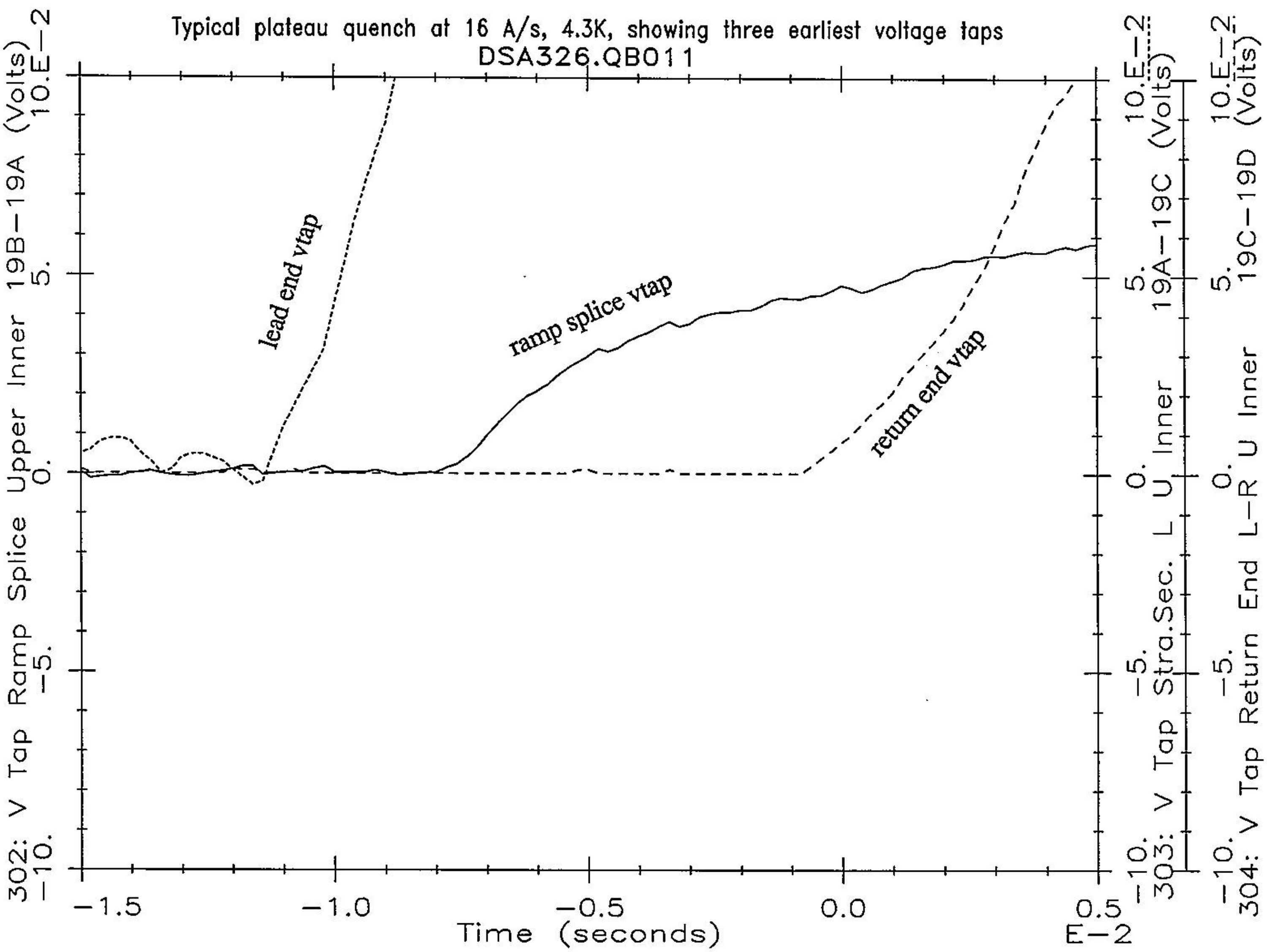
ORIGINATOR: STRAIT/KOSKA
DRAWN: R.DIXON 10/10/90
CHECKED
APPROVED
USED ON
MATERIAL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DSA3XX
VOLTAGE TAPS
INNER COIL

SCALE: NONE
DRAWING NUMBER: 0102-MB-263907
REV. B
CREATED WITH I-DEAS 4.1 USER NAME: SPUD

INCHES METRIC



Typical plateau quench at 16 A/s, 4.3K, showing three earliest voltage taps
DSA326.QB011
302: V Tap Ramp Splice Upper Inner 19B−19A (Volts)
303: V Tap Stra.Sec. L U Inner 19A−19C (Volts)
304: V Tap Return End L−R U Inner 19C−19D (Volts)
10.E−2
Time (seconds)
E−2
lead end vtap
ramp splice vtap
return end vtap

Figure 3

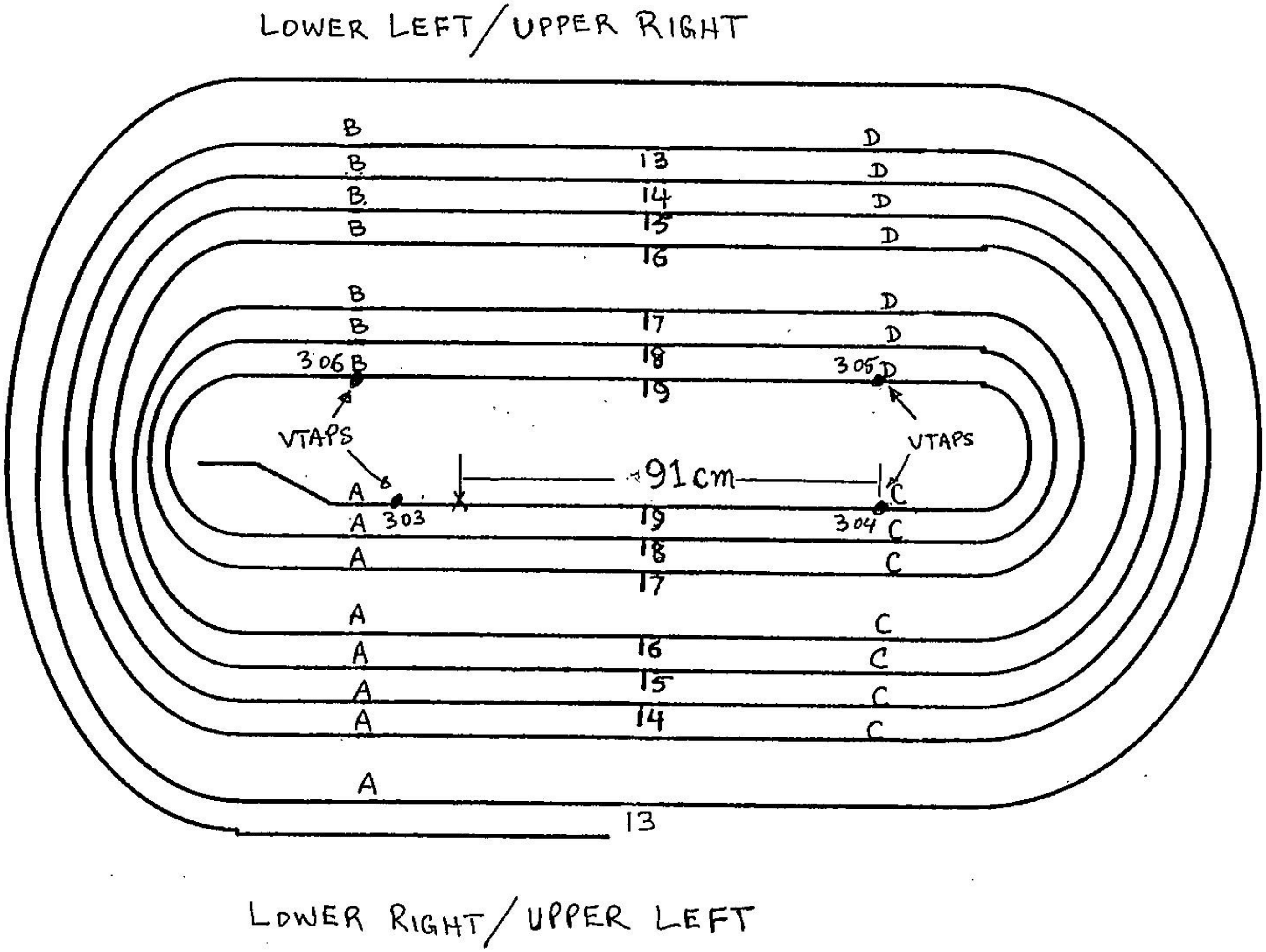

LOWER LEFT/UPPER RIGHT
B
B
B
B
B
B
306 B
VTAPS
A
A 303
A
A
A
A
A
A
13
14
15
16
17
18
19
91cm
19
18
17
16
15
14
13
D
D
D
D
D
D
305 D
VTAPS
C
304 C
C
C
C
C
C
LOWER RIGHT/UPPER LEFT

Figure 4

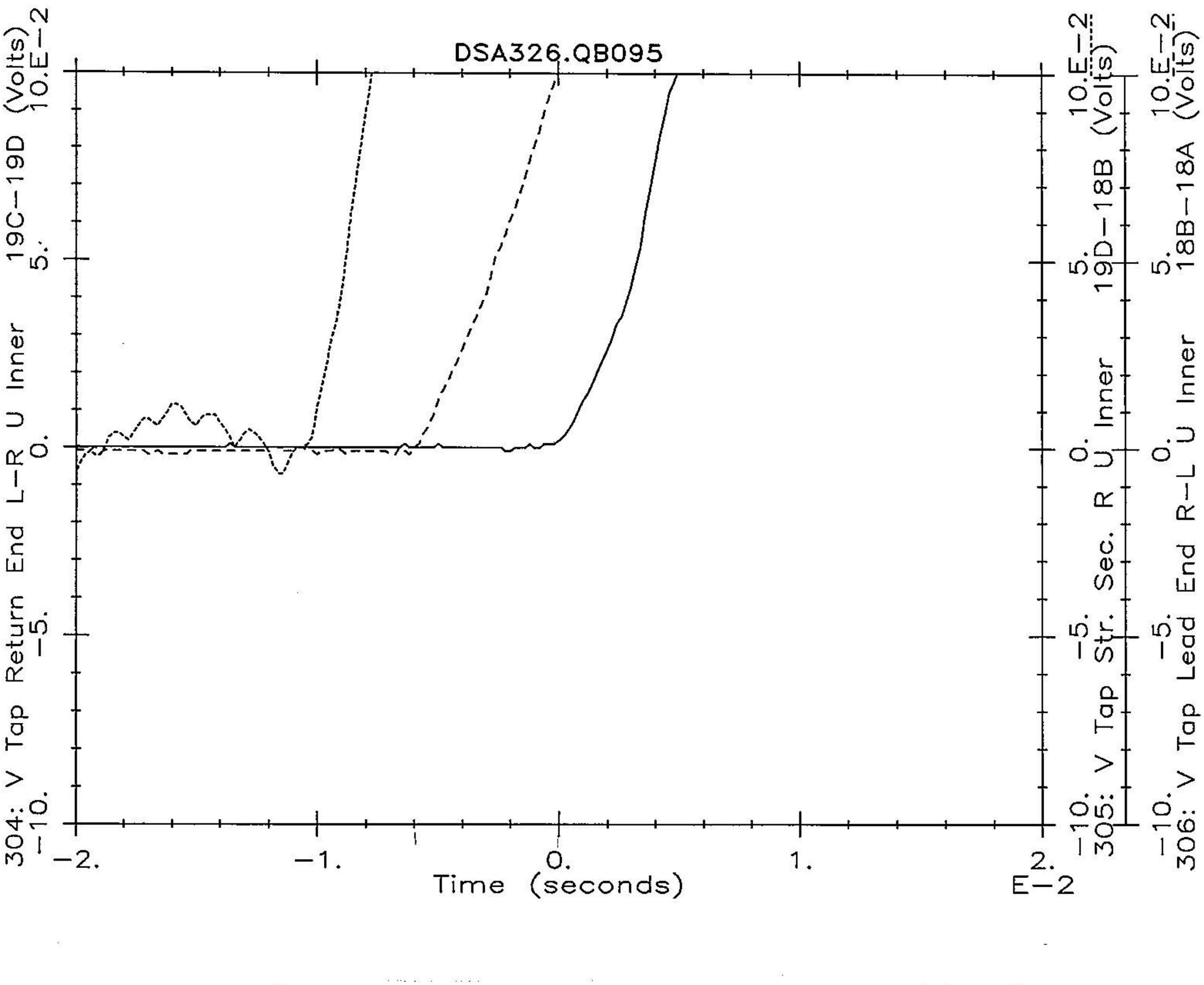
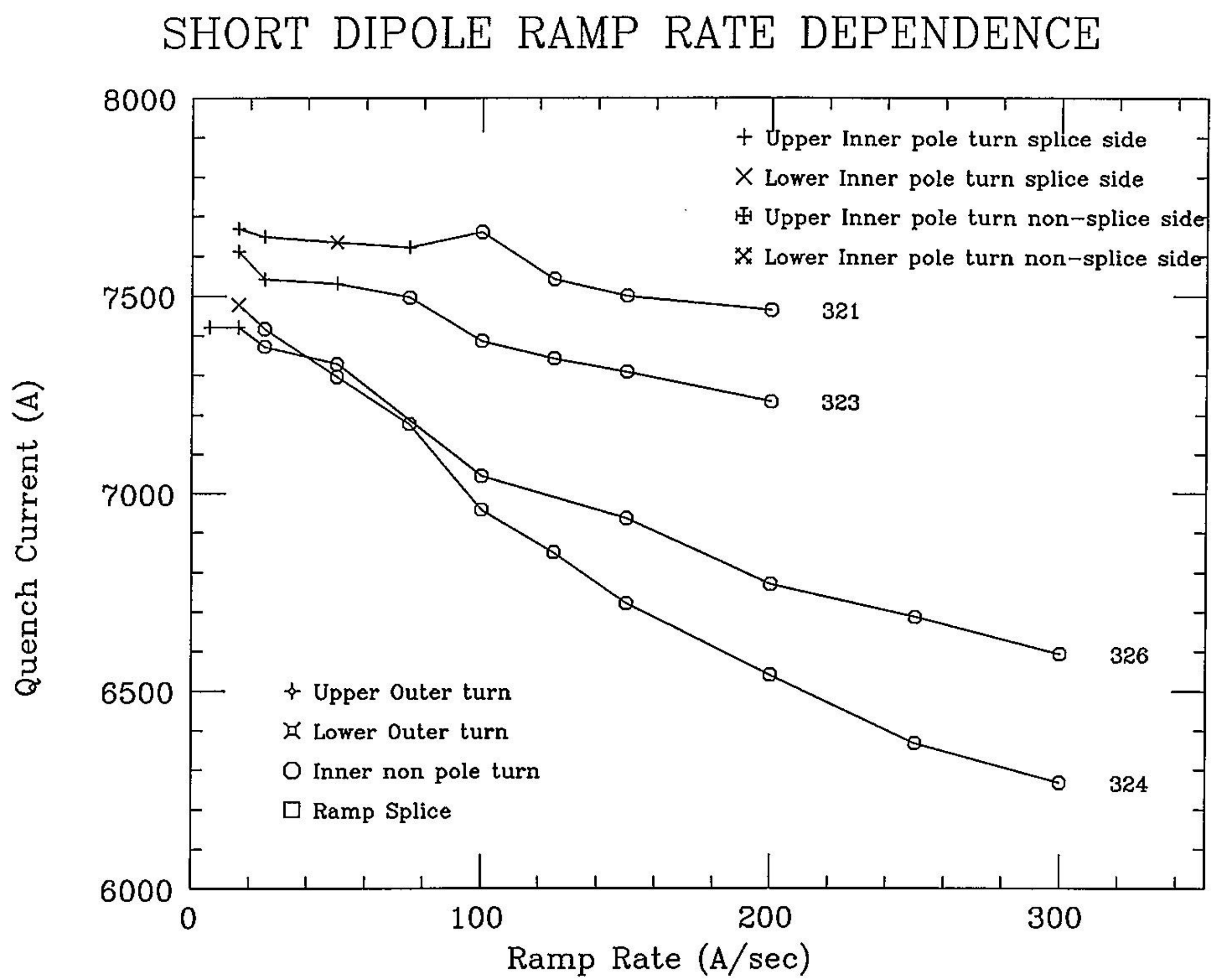


Figure 5: Typical plateau quench on non ramp-splice side of the coil



SHORT DIPOLE RAMP RATE DEPENDENCE
Quench Current (A)
Ramp Rate (A/sec)
8000
7500
7000
6500
6000
0
100
200
300
Upper Inner pole turn splice side
Lower Inner pole turn splice side
Upper Inner pole turn non-splice side
Lower Inner pole turn non-splice side
Upper Outer turn
Lower Outer turn
Inner non pole turn
Ramp Splice
321
323
326
324

Figure 6

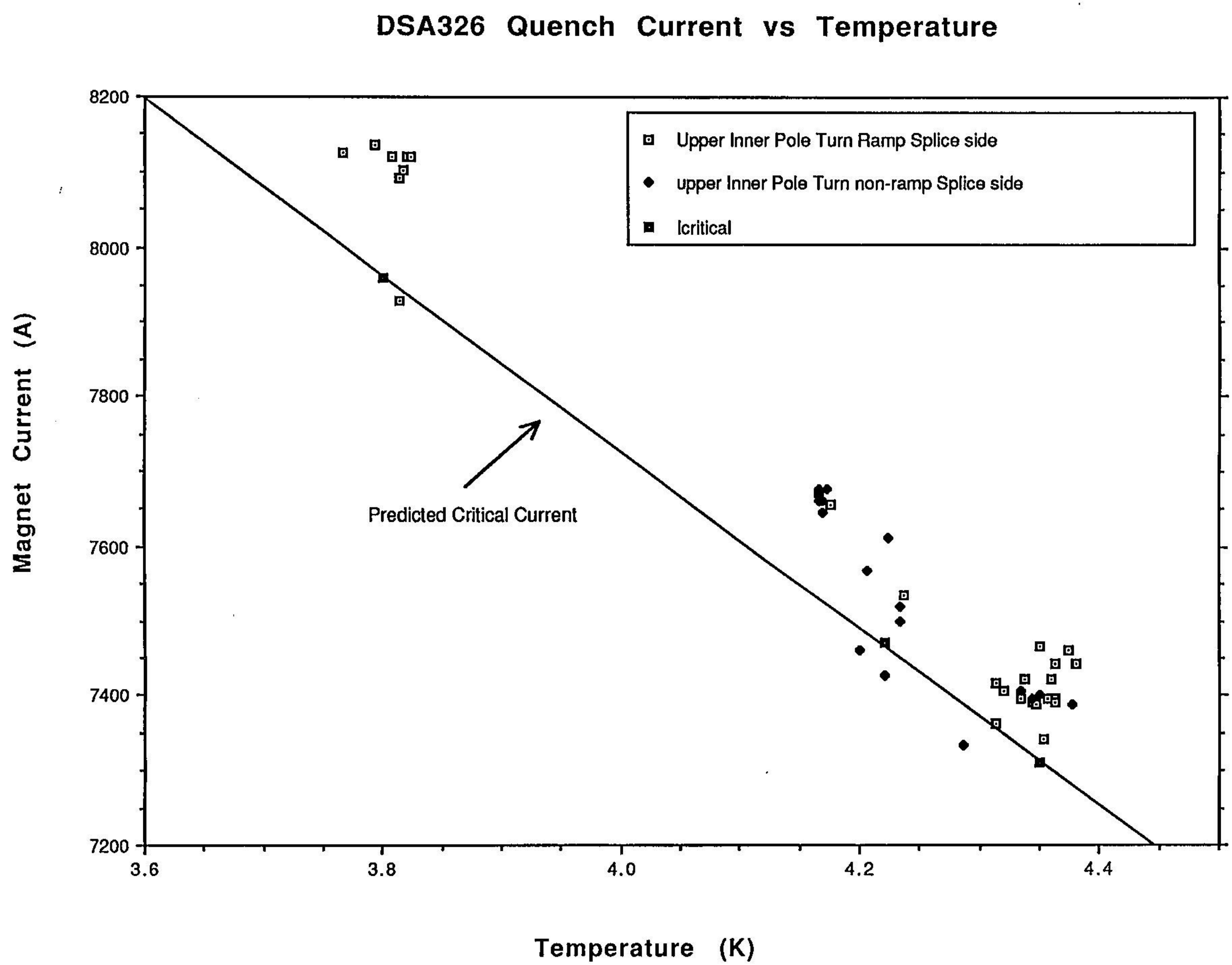

DSA326 Quench Current vs Temperature
Upper Inner Pole Turn Ramp Splice side
upper Inner Pole Turn non-ramp Splice side
Icritical
Predicted Critical Current
Magnet Current (A)
8200
8000
7800
7600
7400
7200
3.6
3.8
4.0
4.2
4.4
Temperature (K)

Figure 7