10/15/05
TD-05-060

HFDA06 Test Summary

S. Feher, B. Bordini, G. Ambrosio, N. Andreev, R. Carcagno, D. Chichili, V.V. Kashikhin, M.J. Lamm, I. Novitski, D. Orris, Y. Pischalnikov, C. Sylvester, M. Tartaglia, J.C. Tompkins, G. Velev, A.V. Zlobin

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1. Introduction

HFDA06 was completed on July 18th, 2005. The magnet was installed into the VMTF dewar and it was electrically checked by the end of July 22nd, 2005. The VMTF dewar was filled with liquid helium on August 23rd, 2005. First thermal cycle of the magnet has been completed on August 30th . There were no modifications introduced for the second test cycle. The second thermal cycle was started on September 9th and it was finished on September 16th. The magnet still remained in cold condition for PS tests. Finally the magnet has been removed from the VMTF dewar on October 21sr, 2005.

2. Quench History

The magnet test program has started with quench training at 20 A/s ramp rate. The first quench was at relatively high current 14754 A. This quench current was even higher than the first quench current of HFDA05. This magnet exhibited a steady training. It took 10 quenches to train it. The highest quench current at 4.5K (20A/s) was 16448A. After a successful training we continued the program with ramp rat studies. Since there was a cryogenic problem with VMTF we had to perform a thermal cycle. After we cooled down the magnet again to 4.5K we started our test program again with magnet training. The magnet remembered its previous training so it took only two quenches to reach the previous quench current plateau. Next step was to train tha magnet at 2.2 K. At 2.2 K the magnet reached more than 10 T magnetic field. We performed ramp rate dependence studies and than gradually warmed up the magnet to do temperature dependence studies. At 4.5K we quenched the magnet again few times. In this test cycle we also performed heater studies and energy loss and splice measurements.

The quench history plot is presented in Figure 2-1. and in Table 2-1.

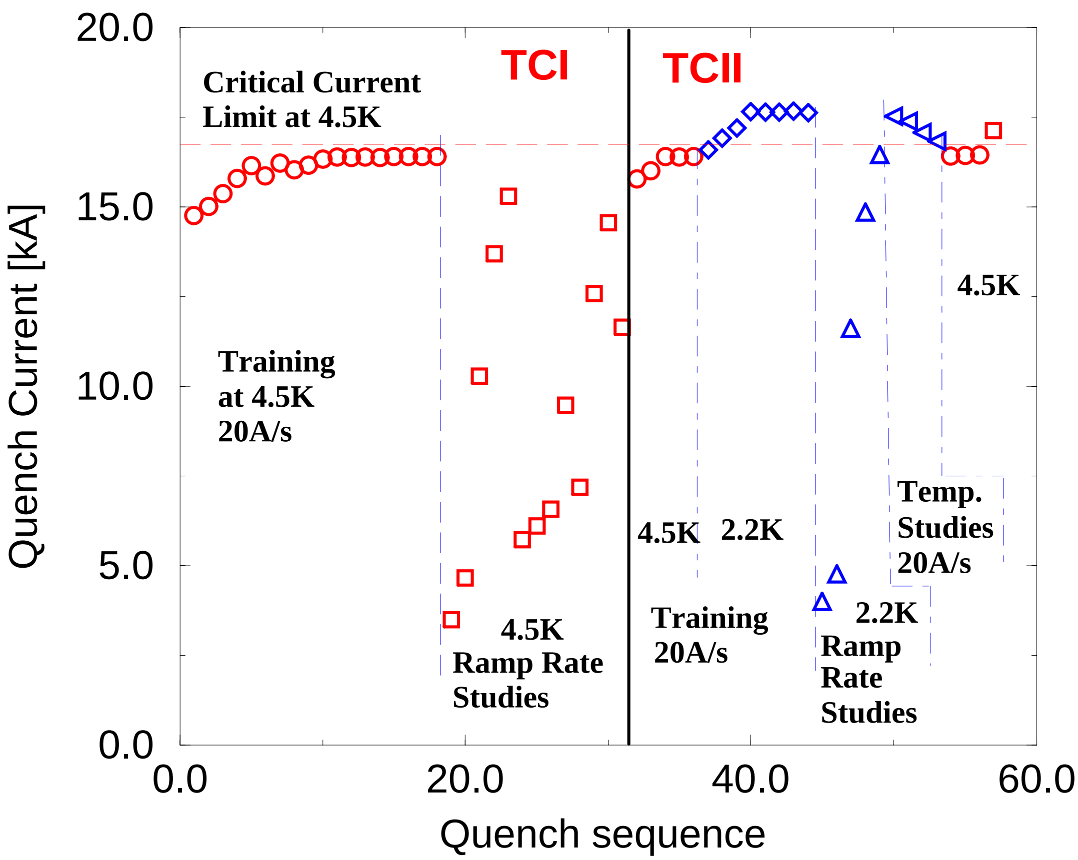

Figure 2-1. Quench history

Table 2-I. Quench summary table

File	Current [A]	dIdt	t_{quench}	MIITs	QDC	1st VTseg	Mag Temp Bot Left	Comment
hfda06.Quench.050823144035.986	13	0	0.0003	0.00	HcoilHcoil		4.432	0A trip to check heater firing sequence and the heater voltages.
hfda06.Quench.050823150648.612	16	0	0.0000	0.00	HcoilHcoil		4.434	0A manual trip to check the heaters
hfda06.Quench.050824093825.957	11	0	0.0000	0.03	SlWcoil		4.474	It was a trip due to unplugging a cable.
hfda06.Quench.050824094607.954	182	48	-0.0232	0.03	HcoilHcoil		4.472	Trip during balancing AQDs.
hfda06.Quench.050824101711.075	1017	0	0.0007	0.08	HcoilHcoil		4.466	1000A manual trip to check the signals.
hfda06.Quench.050824165245.674	1020	0	-0.0070	0.09	SlWcoil		4.437	1000A manual trip
hfda06.Quench.050824171339.789	5028	0	-0.1200	4.17	HcoilHcoil		4.438	5000A heater induced quench, 300V shfu
hfda06.Quench.050824203101.786	**14811**	0	-0.0024	9.12	HcoilHcoil	Q14i15_Q19i15	4.434	1st quench, 4.5K, Iq=14753.6A, 20a/sec
hfda06.Quench.050824211210.128	**15072**	20	-0.0027	9.38	HcoilHcoil	Q14i14_Q1i14	4.441	2nd quench, Iq=15010.6A, 20a/sec, 4.5K
hfda06.Quench.050825084842.444	**15429**	20	-0.0025	9.68	HcoilHcoil	Q14i14_Q1i14	4.444	testing on existing data file
hfda06.Quench.050825092912.398	**15861**	20	-0.0028	10.10	HcoilHcoil	Q14i14_Q1i14	4.444	4th quench, Iq=15794.4, 20A/s, 4.5K
hfda06.Quench.050825095712.461	**16214**	20	-0.0021	10.25	HcoilHcoil	Q14i14_Q1i14	4.452	5th quench, Iq=16145.5A, 20A/s, 4.5K
hfda06.Quench.050825103113.609	**15930**	20	-0.0020	9.96	HcoilHcoil	Q14i14_Q1i14	4.440	6th quench, Iq=15860A, 20A/sec, 4.5K
hfda06.Quench.050825110451.635	**16285**	20	-0.0022	10.35	HcoilHcoil	Q14i14_Q1i14	4.445	7th quench, Iq=16218.4A, 20A/sec, 4.5K
hfda06.Quench.050825113906.062	**16104**	20	-0.0021	10.15	HcoilHcoil	Q14i14_Q1i14	4.443	8th quench, Iq=16037.7A, 20A/s, 4.5K
hfda06.Quench.050825121521.414	**16232**	20	-0.0022	10.27	HcoilHcoil	Q14i14_Q1i14	4.439	9th quench, Iq=16163.7A, 20A/s, 4.5K
hfda06.Quench.050825124552.362	**16401**	0	-0.0017	10.26	HcoilHcoil	Q14i14_Q1i14	4.432	Quench #10 20A/sec 4.5K Iq=16331.7A Ramp #10
hfda06.Quench.050825131707.861	**16467**	20	-0.0013	10.20	HcoilHcoil	Q1i15_Q14i15	4.434	Quench #11 4.5K 20A/sec Iq=16399.5
hfda06.Quench.050825140012.075	**16440**	20	-0.0014	10.23	HcoilHcoil	Q1i15_Q14i15	4.431	12th quench, Iq=16373.5A, 20A/sec, 4.5K@Ñ¸ @ÑÐ
hfda06.Quench.050825143933.221	**16463**	20	-0.0014	10.24	HcoilHcoil	Q1i15_Q14i15	4.435	Quench #13 4.5K 20A/sec Iq=16397
hfda06.Quench.050825151531.312	**16452**	20	-0.0014	10.25	HcoilHcoil	Q1i15_Q14i15	4.431	Quench #14 4.5K 20A/sec Iq=16381.3Ato
hfda06.Quench.050825155304.413	**16472**	20	-0.0014	10.24	HcoilHcoil	Q1i15_Q14i15	4.426	15th quench, Iq=16403 A, 20A/s, 4.5K
hfda06.Quench.050825162159.572	**16481**	20	-0.0011	10.21	HcoilHcoil	Q1i15_Q14i15	4.428	16th quench, Iq=16412.9A, 20A/sec, 4.5K
hfda06.Quench.050825164612.539	**16481**	20	-0.0013	10.23	HcoilHcoil	Q1i15_Q14i15	4.426	17th quench, Iq=16414.2A, 20A/sec, 4.5K
hfda06.Quench.050825171510.859	**16479**	20	-0.0014	10.28	HcoilHcoil	Q1i15_Q14i15	4.430	18th Quench, Iq=16411.3A, 20A/sec, 4.5K

hfda06.Quench.050825173559.190	**3418**	301	-0.3439	4.70	WcoilGnd	QMS6_Q1i15	4.418	19th quench, Iq~3000A, 300A/sec, 4.5K
hfda06.Quench.050825175140.197	**4682**	200	-0.1355	3.92	HcoilHcoil	Q19i14_Q14i14	4.421	20th quench, Iq=4651.1A, 200A/sec, 4.5K
hfda06.Quench.050825180957.710	**10328**	150	-0.0071	5.19	WcoilIdot	Q14i14_Q1i14	4.423	21st quench, Iq=10278.8A, 150A/sec, 4.5K
hfda06.Quench.050825182716.082	**13760**	0	-0.0028	7.94	HcoilHcoil		4.424	22nd Quench, Iq=13700.9A, 100A/sec, 4.5K
hfda06.Quench.050825185405.687	**15356**	50	-0.0017	9.23	HcoilHcoil		4.422	23rd quench, Iq=15300A, 50A/sec, 4.5Ko
hfda06.Quench.050825191215.309	**5762**	175	-0.0658	3.62	WcoilIdot	Q19i15_QNS2	4.422	24th quench, Iq=5722.2A, 175A/sec, 4.5K
hfda06.Quench.050825192922.282	**6150**	171	-0.0546	3.69	HcoilHcoil	Q19i15_QNS2	4.421	25th quench, Iq=6104.9A, 170A/s, 4.5Ko
hfda06.Quench.050825194425.836	**6622**	0	-0.0368	3.49	HcoilHcoil	QPS2_Q19i14	4.424	26th Quench, Iq=6577.1A, 160A/sec, 4.5K
hfda06.Quench.050825200117.611	**9522**	155	-0.0101	4.71	WcoilIdot	Q1i15_Q14i15	4.425	27th quench, Iq=9470.5A, 155A/sec, 4.5K
hfda06.Quench.050826074532.953	**7234**	0	-0.0248	3.54	HcoilHcoil	QPS2_Q19i14	4.448	28th Quench, Iq=7187.4A, 160A/s, 4.5K
hfda06.Quench.050826080148.391	**12604**	126	-0.0056	7.18	WcoilIdot	Q1i15_Q14i15	4.442	29th quench, Iq=12548.7A, 125A/s, 4.5K
hfda06.Quench.050826081944.224	**14617**	75	-0.0018	8.51	HcoilHcoil		4.446	30th quench, Iq=14557.9A, 75A/sec, 4.5K4.50987
hfda06.Quench.050826084511.796	**11705**	0	-0.0069	6.47	WcoilIdot	Q14i14_Q1i14	4.439	31st quench, Iq=11649.6A, 137A/s, 4.5K
hfda06.Quench.050829170654.530	**16596**	20	-0.0017	10.53	HcoilHcoil		4.478	32nd quench, Iq=16527A, 20A/sec, 4.5K
hfda06.Quench.050829174046.246	**15070**	0	-0.1325	39.08	HcoilHcoil		4.491	SHFU study, 15000A, 4.5K, 90V is the value which was able to quewnch the magnet
hfda06.Quench.050829180917.891	**15073**	0	-0.0329	16.29	WcoilIdot		4.494	Iq=15000A, 4.5K, SHFU = 200V
hfda06.Quench.050829183403.088	**15065**	0	-0.0224	13.84	HcoilHcoil		4.493	SHFU = 300V, 15000A, 4.5K
hfda06.Quench.050829190311.364	**15073**	0	-0.0459	19.31	HcoilHcoil		4.492	SHFU=140V, 15000A, 4.5K
hfda06.Quench.050829192623.506	**11608**	0	-0.0881	17.42	HcoilHcoil		4.482	I=11550A, 4.5K, SHFU=140V
hfda06.Quench.050829194431.316	**11610**	0	-0.2148	34.50	HcoilHcoil		4.483	SHFU=120V, I=11550A, 4.5K
hfda06.Quench.050829195644.033	**11604**	0	-0.0456	11.70	HcoilHcoil		4.482	SHFU=200V, 4.5K, I=11550A
hfda06.Quench.050830172442.198	**11609**	0	-0.0328	9.96	HcoilHcoil		4.440	11550A, SHFU=300V, 4.5K
hfda06.Quench.050830174355.211	**6642**	0	-0.2694	13.80	HcoilHcoil		4.433	6600A, SHFU=170V, 4.5K
hfda06.Quench.050830175632.000	**6639**	0	-0.1004	6.35	HcoilHcoil		4.429	6600A, SHFU=200V, 4.5K
hfda06.Quench.050830180555.891	**6643**	0	-0.0588	4.51	HcoilHcoil		4.431	6600A, SHFU=300V, 4.5K
hfda06.Quench.050830181637.154	**6637**	0	-0.0486	4.05	HcoilHcoil		4.430	6600A, SHFU=400V, 4.5K
hfda06.Quench.050906120043.885	1014	0	-0.0021	0.08	SlWcoil		4.449	1000A manual trip
hfda06.Quench.050906134934.933	**15831**	19	-0.0022	9.94	HcoilHcoil		4.460	TC2 1st quench, 20A/sec, 4.5K, Iq=15775.6A
hfda06.Quench.050906141634.197	**16063**	20	-0.0027	10.23	HcoilHcoil		4.475	2nd quench after TC, 20A/sec, 4.5K, Iq=16005.3A
hfda06.Quench.050906144607.928	**16468**	20	-0.0013	10.25	HcoilHcoil		4.470	3rd quench after TC, Iq=16411A, 20A/sec, 4.5K
hfda06.Quench.050906151044.418	**16446**	20	-0.0013	10.26	HcoilHcoil		4.479	4th quench, Iq=16391.5, 4.5K, 20A/sec after TC
hfda06.Quench.050906153254.533	**16469**	20	-0.0013	10.25	HcoilHcoil		4.481	Just use this file as an example.½ò@ˆK¬
hfda06.Quench.050908122546.141	**16664**	19	-0.0045	11.46	HcoilHcoil	Q1i15_Q14i15	2.165	Quench # 6 Iq=16595.5A 2.2K 20A/sec @Ñ

hfda06.Quench.050908125723.648	**16996**	20	-0.0046	11.83	SlWcoil	Q14i14_Q1i14	2.165	Quench #7 Iq=16700 2.2K 20A/sec after TC
hfda06.Quench.050908133713.151	17267	20	-0.0020	11.31	HcoilHcoil		2.165	Coef
hfda06.Quench.050908140305.385	17722	20	-0.0011	11.46	HcoilHcoil		2.160	check enterComment separetely
hfda06.Quench.050908144217.908	17716	20	-0.0010	11.37	HcoilHcoil		2.166	Quench # 10 Iq=17644.2 2.2K 20A/sec after TC
hfda06.Quench.050908151311.421	17718	20	-0.0008	11.38	HcoilHcoil		2.165	Quench #11 Iq=17647A 20A/sec 2.2K after TC
hfda06.Quench.050908154333.194	17738	-1103	-0.0013	11.49	HcoilHcoil		2.166	Quench 12 Iq=17665.8 2.2K 20A/sec after TC
hfda06.Quench.050908161031.648	17709	20	-0.0008	11.35	HcoilHcoil		2.166	Quench #13 Iq=17636.5 2.2K 20A/sec after TC
hfda06.Quench.050908162700.566	3994	280	-0.1946	3.85	WcoilGnd	Q19i15_QNS2	2.176	Quench #14 Iq=4003.7 2.2K 300A/sec after TC
hfda06.Quench.050908165804.930	4796	201	-0.1035	3.39	HcoilHcoil	Q19i14_Q14i14	2.166	Quench# 15 Iq=4767.7 2.2K 200A/sec after TC
hfda06.Quench.050908171807.796	11670	151	-0.0050	6.21	WcoilIdot	Q14i14_Q1i14	2.167	Quench 16 Iq=11616.5 150A/sec 2.2K after TC
hfda06.Quench.050908173347.022	14926	100	-0.0024	9.01	HcoilHcoil		2.167	Quench #17 Iq=14865A 100A/sec 2.2K after TC0987
hfda06.Quench.050908175204.214	16535	50	-0.0014	10.33	HcoilHcoil		2.178	Quench# 18 Iq=16468 2.2K 50A/sec after TC
hfda06.Quench.050908185021.901	17599	20	-0.0013	11.38	HcoilHcoil		2.423	19th quench, 2.5K, 20A/sec, Iq=17525A
hfda06.Quench.050908200158.229	17454	20	-0.0008	11.15	HcoilHcoil		2.967	20th quench, 3K, 20A/sec, Iq=17381.8
hfda06.Quench.050908210207.028	17145	20	-0.0010	10.92	HcoilHcoil		3.409	Quench #21 Iq=17078 T=3.45K 20A/sec, after TC
hfda06.Quench.050908213715.801	16896	20	-0.0011	10.73	HcoilHcoil		3.977	Quench #22 Iq=16827.6 20A/sec 4K after TC
hfda06.Quench.050909104016.117	16495	20	-0.0011	10.22	HcoilHcoil		4.446	Quench #23 Iq= 16427.4 4.5K 20A/sec after TC
hfda06.Quench.050909110929.627	16509	20	-0.0013	10.25	HcoilHcoil		4.440	Quench #24 Iq=16442 4.5K 20A/sec after TC
hfda06.Quench.050909113238.124	16515	20	-0.0013	10.30	HcoilHcoil		4.439	Quench #25 Iq=16448.1A 4.5K 20A/sec
hfda06.Quench.050909124749.081	17200	4	-0.0010	10.91	HcoilHcoil		4.454	25th qeunch, 5A/sec, Iq=17133.1, 4.5K
hfda06.Quench.050909131825.194	15411	51	-0.0017	9.27	HcoilHcoil		4.424	27th qeunch, 50A/s, 4.5K, Iq=15349.2Ao
hfda06.Quench.050909133541.864	13848	100	-0.0027	7.97	HcoilHcoil		4.425	Quench #28 Iq=13792.5 4.5K 100A after TC
hfda06.Quench.050909155301.963	17141	19	-0.0014	10.97	HcoilHcoil		4.445	29th quench, 20A/sec, 4.5K, Iq=17072.2A, after cycling up-down coiple times between 0A and 15700A
hfda06.Quench.050909160945.252	3325	0	-0.4032	4.97	HcoilHcoil		4.425	Vmin study 200V initiated a quench
hfda06.Quench.050909162401.286	3323	0	-0.1010	1.63	WcoilGnd		4.416	300V heater initated quench at 4.5K and 3300A
hfda06.Quench.050909163004.190	3314	0	-0.0760	1.35	HcoilHcoil	Q19i14_Q14i14	4.417	SHFU=400V, 3300A, 4.5K
hfda06.Quench.050909165000.160	15063	0	-0.0190	13.20	HcoilHcoil		4.421	Heater study, 15000A, SHFU=400V, 4.5K
hfda06.Quench.050909165836.130	11607	0	-0.0255	8.94	HcoilHcoil		4.428	Heater study, 400V, 11550A, 4.5K
hfda06.Quench.050909170655.559	5037	0	0.0006	7.17	SlWcoil		4.423	QI study at 5000A, 400V, dump delayed to 1sec, no heater delay, manual trip was initiated
hfda06.Quench.050909171727.997	7038	0	-0.0018	12.01	SlWcoil		4.419	QI study, SHFU=400V, 7000A, dump delay 1sec no heater delay, manual trip

hfda06.Quench.050909172524.157	9051	0	0.0007	15.47	HcoilHcoil		4.427	QI study, 9000A, SHFU=400V, dump delayed to 1sec, no heater delay
hfda06.Quench.050909173415.234	11054	0	0.0004	18.12	SlWcoil	V1_TrigCvtB1	4.438	QI study, 11000A, SHFU=400V, no heater delay, dump delay to 1sec, manual trip
hfda06.Quench.050909174444.780	13066	0	0.0008	19.53	HcoilHcoil	V1_TrigCvtB1	4.446	QI study, 13000A, SHFU=400V, 1sec dump delay, no heater delay, manual trip
hfda06.Quench.050909175438.812	15072	0	0.0007	19.44	HcoilHcoil	V1_TrigCvtB1	4.478	QI study, 15000A, SHFU=400V, 1sec dump delay, no heater delay, manual trip
hfda06.Quench.050914111919.848	5945	5	0.0000	0.73	WcoilIdot	V1_TrigCvtB1	2.162	There was a quench ar a trip unfortunatelly I was not close to the computer.
hfda06.Quench.050914124233.539	18174	5	-0.0014	12.25	HcoilHcoil	V1_TrigCvtB1	2.162	30th quench, 5A/s, 2.2K, Iq=18097.3A
hfda06.Quench.050914135301.500	17908	5	-0.0014	11.93	HcoilHcoil	V1_TrigCvtB1	2.162	31st quench, 5A/s, 2.2K, Iq=17834.5A
hfda06.Quench.050914150613.036	18492	5	-0.0017	12.51	HcoilHcoil	V1_TrigCvtB1	2.162	32nd quench, special ramp rpofile, 0A-17000A-0A-17000A, with 20A/sec, wait for 15 min than 5 A/s to quench, 2.2K, Iq=18413.9A
hfda06.Quench.050914162122.477	18483	4	-0.0013	12.26	HcoilHcoil	V1_TrigCvtB1	2.162	33rd quench, special ramp, 18408.6A
hfda06.Quench.050914191609.530	18514	5	-0.0011	12.27	HcoilHcoil	Q1i15_Q14i15	2.162	34th quench, after splice measurements, 2.2K, first rampe to 17000A with 20A/sec than wait 30min than ramp to quench with 5A/sec,
hfda06.Quench.050915162645.961	4260	-349	-0.2376	5.02	HcoilHcoil	Q19i14_Q14i14	4.438	quench while ramping down during eieo measurements

3. Ramp Rate Dependence

Ramp rate dependence studies are summarized in Figure 3-1. Quench current decreases with increasing ramp rate following a continuous function. This behavior is another confirmation that the magnets are at critical current limits. The shape of this dependence at low current ramp rates suggests that the ramp rate dependence is dominated by the eddy currents losses in the cable which are quite large in these two coils (see Fig.xx). At ramp rates higher than 200 A/s the quench current drops dramatically and practically does not change with the current ramp rate. This behavior indicates that the magnet is limited by high losses and insufficient coil cooling conditions.

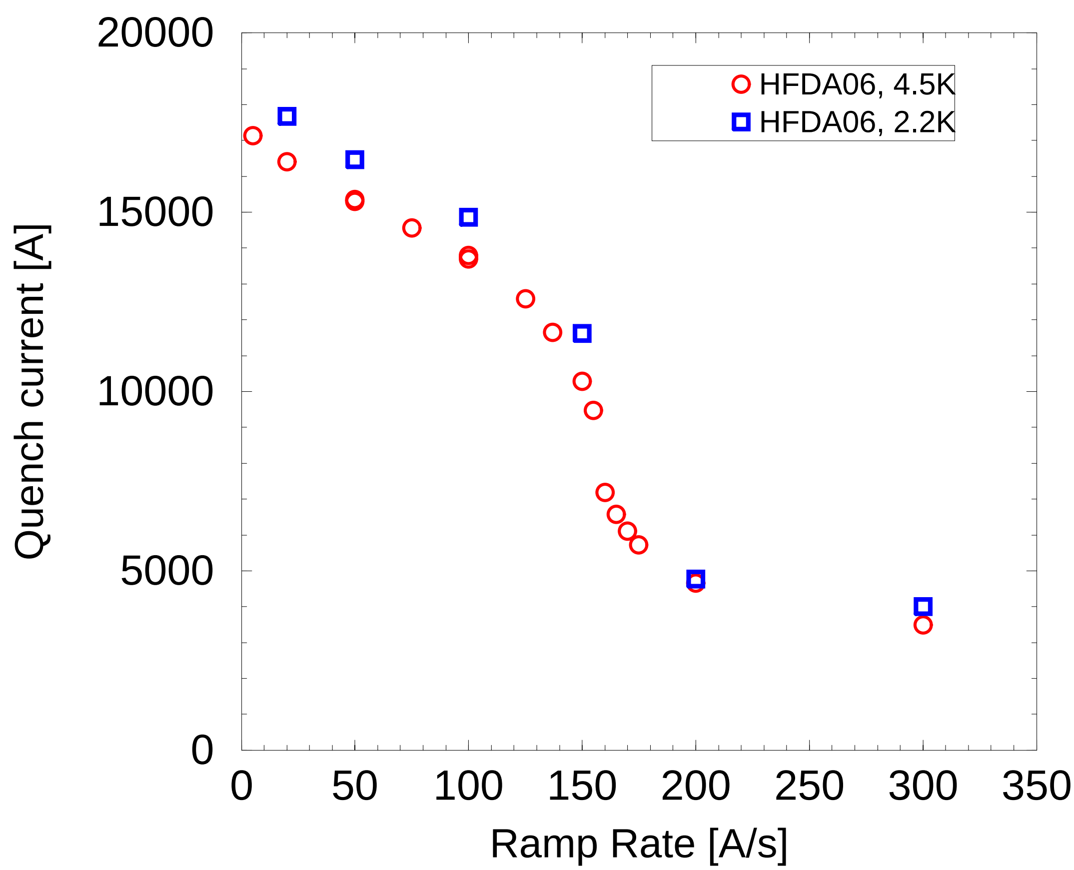

Figure 3-1. Current ramp rate dependence.

4. Temperature Dependence

Perfect temperature dependence was observed for HFDA06. The dependence of magnet quench current vs. temperature for HFDA06 is presented in Fig. 4-1. This dependence was measured during the second thermal cycle after the completion of magnet training at 4.5 K and 2.2 K. The data confirms that the magnet reached its short sample limit at all temperatures from 2.2 K to 4.5 K.

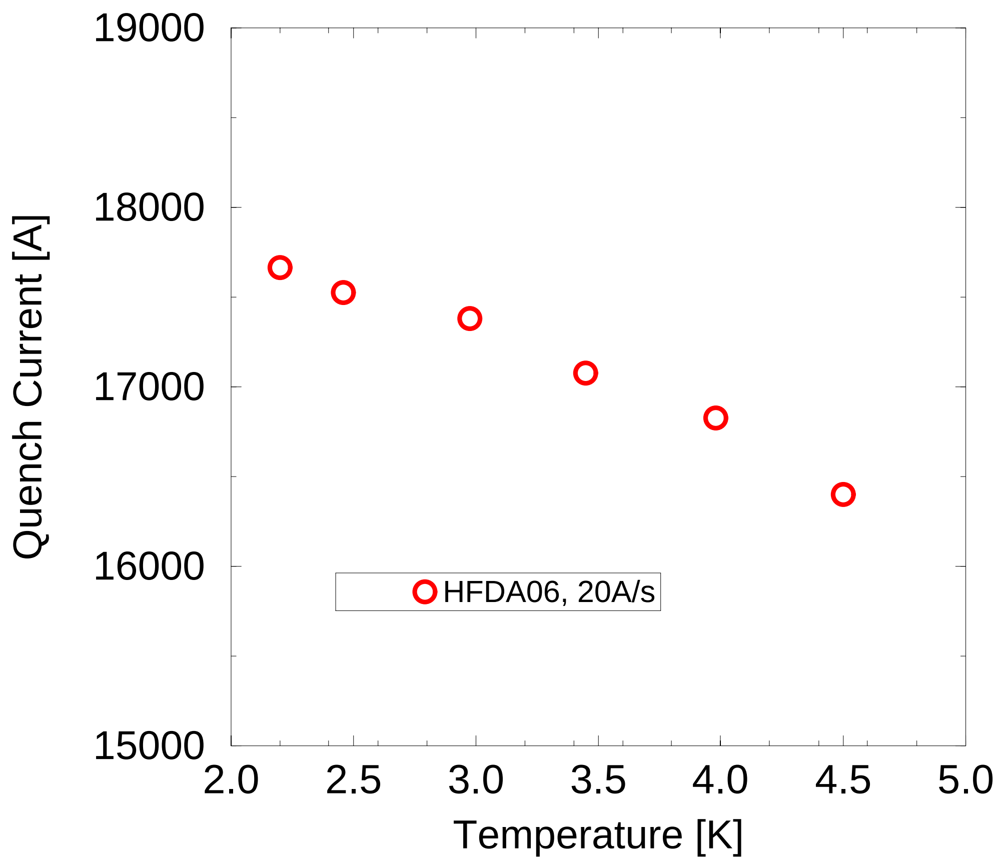

Figure 4-1. Temperature dependence studies.

5. Splice measurement

We performed splice measurements. The current was increased up to 14000 A and the voltage drops across the splices were recorded. Figure 5-1. shows the measurement results.

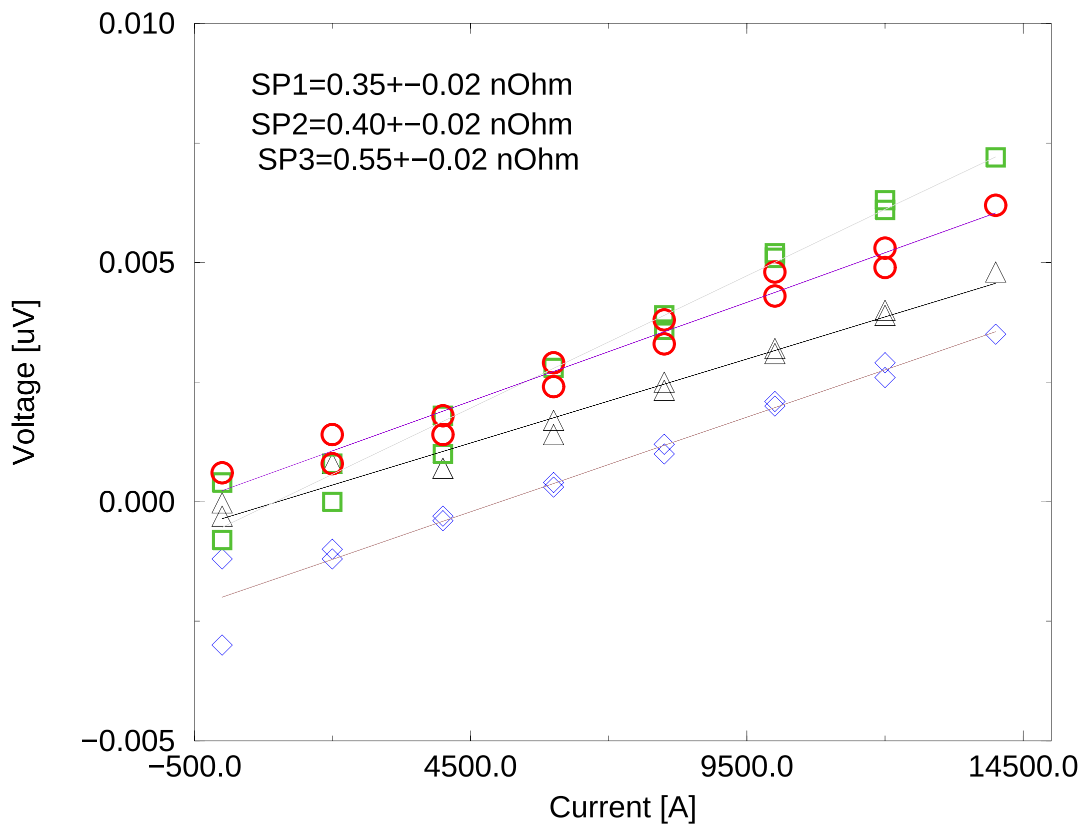

Figure 5-1. Splice measurement results

6. Magnetic measurement

Measurements of magnetic fields in the aperture were performed after cooling down in two thermal cycles. The measurement system was set up above VMTF cryostat and utilized 250 mm long probe (active length), 25 mm in diameter. The probe had a tangential winding for high order harmonics as well as dedicated dipole and quadrupole windings for low order harmonics and bucking. Probe coil voltages were sampled 128 times per rotation using HP3458 DVMs and read on the subsequent rotation. The probe rotation period was ~3s. An additional DVM was used to monitor the magnet current. DVMs were triggered simultaneously by an angular encoder on the probe shaft, synchronizing measurements of the field and current. A probe centering correction was performed by zeroing the unallowed by the dipole symmetry a_8/a_{10} and b_8/b_{10}. At constant current, centering was performed for each rotation. In current cycles it was done using the data taken between 2 kA and 3 kA on both up and down ramps in the first cycle. The main field was assumed to be pure normal (no skew dipole component) and a corresponding field angle was assigned. The field in the magnet body was represented in terms of harmonic coefficients defined by the expansion:

$$B_y + iB_x = B_1 \times 10^{-4} \sum_{n=1}^{\infty} (b_n + ia_n)\left(\frac{x+iy}{r_0}\right)^{n-1},$$

where B_x and B_y are horizontal and vertical transverse field components, B_1 is the dipole field component, and b_n and a_n are the $2n$-pole coefficients at a reference radius r_0.

A right-hand Cartesian coordinate system was defined with Z-axis at the center of the magnet aperture, pointing from return to lead end and the Y-axis coinciding with the dipole field vector. In this note the field harmonics are reported at r_0=10 mm and Z=0 mm (magnet center).

Z-scans

The Z-scan was performed at -0.50, -0.25, 0, 0.25, 0.50, 0.75, 1.00 m coordinates at ±10 A current during the “warm” measurements. During the “cold” measurements, the Z-scan was performed at the same positions at 4000 A and 10000 A at ramps up and down following the pre-cycle up to 12000 A. Figure 6-1 to Figure 6-2 present the main field components and transfer functions and Figure 6-3 to Figure 6-10 show low-order harmonics, normalized by the main field component at Z=0, averaged between positive and negative currents for the “warm” measurements and between up and down ramps for the “cold” measurements.

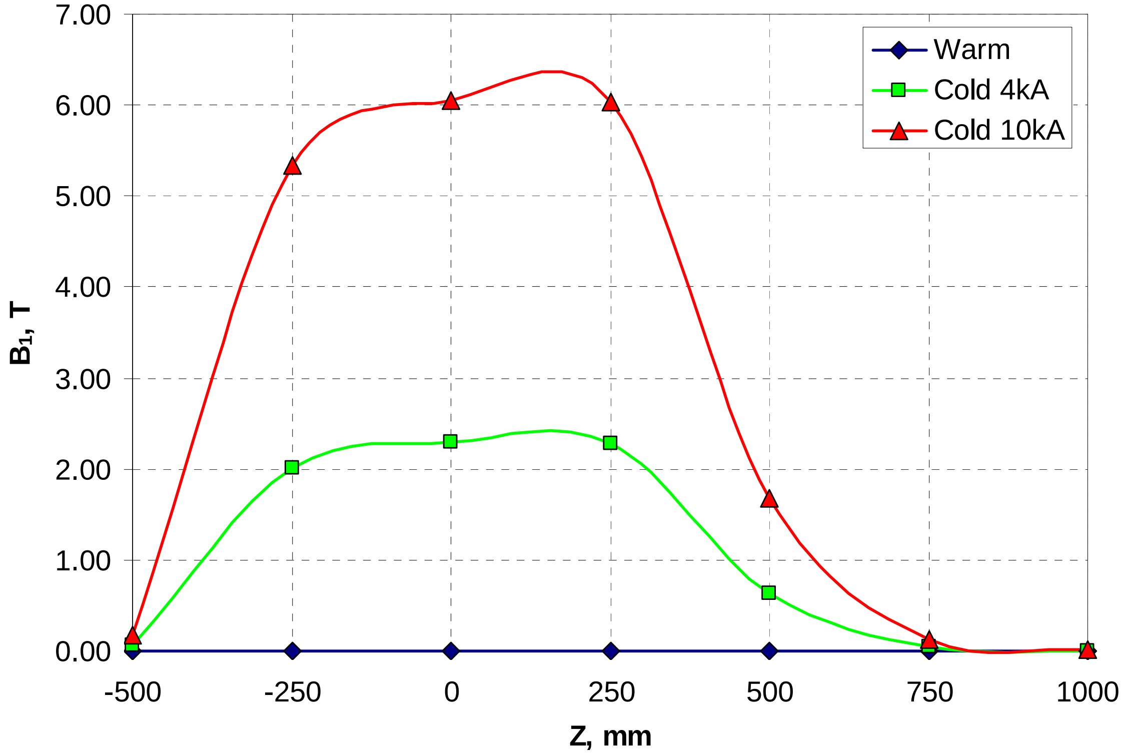

Figure 6-1. Main field component along Z-axis.

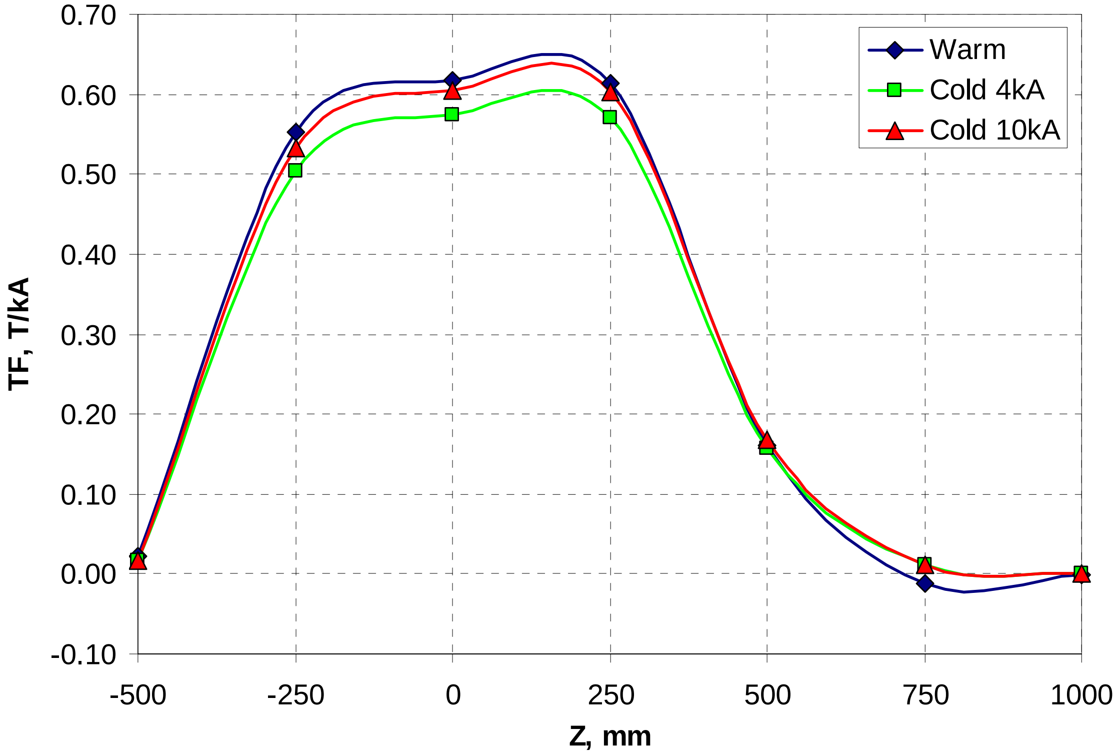

Figure 6-2. Transfer function along Z-axis.

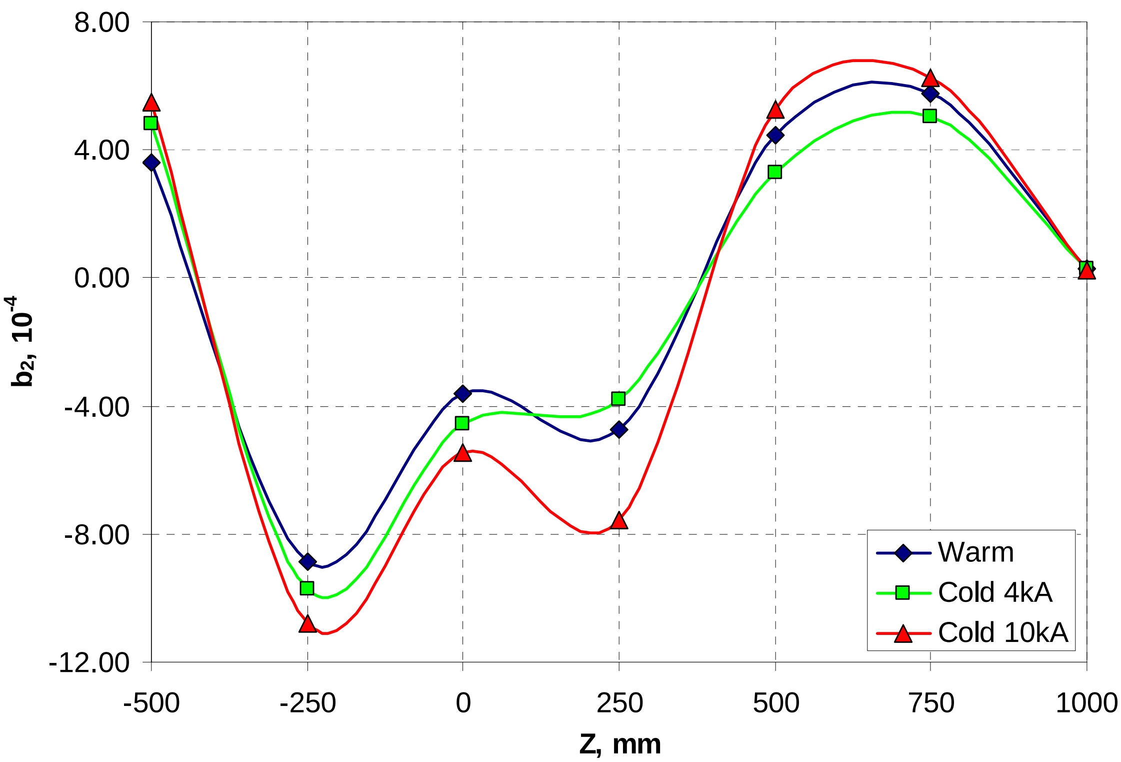

Figure 6-3. Normal quadrupole along Z-axis.

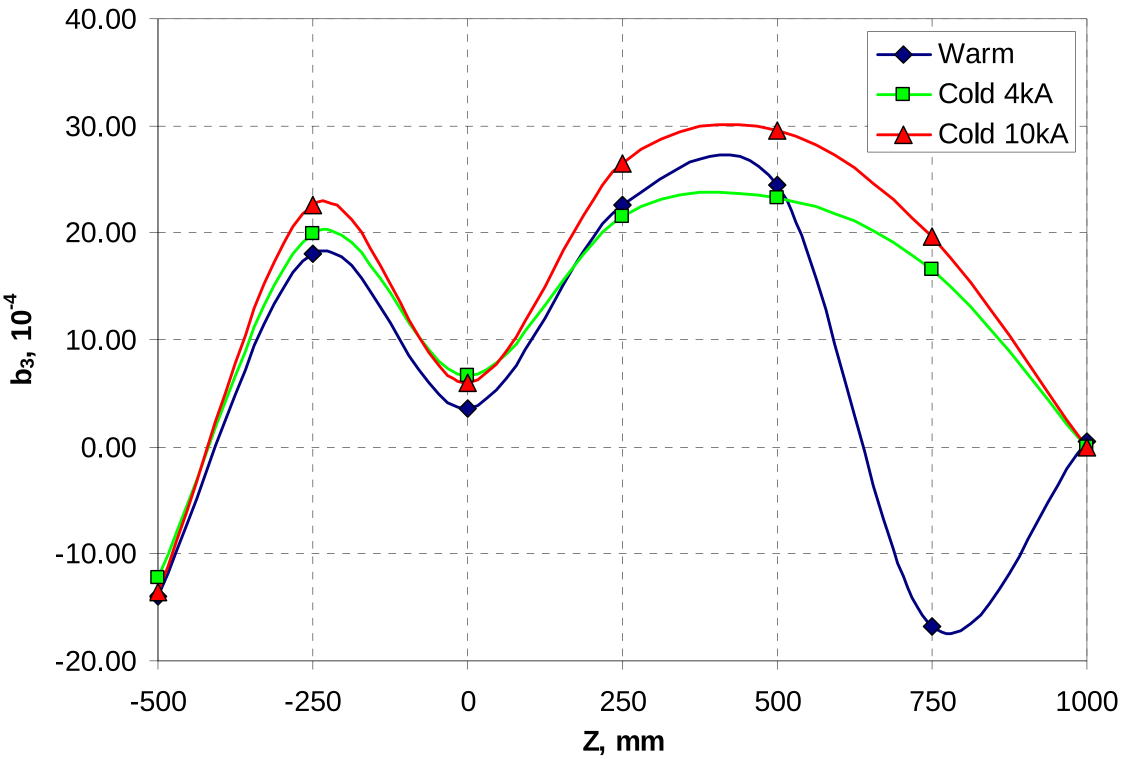

Figure 6-4. Normal sextupole along Z-axis.

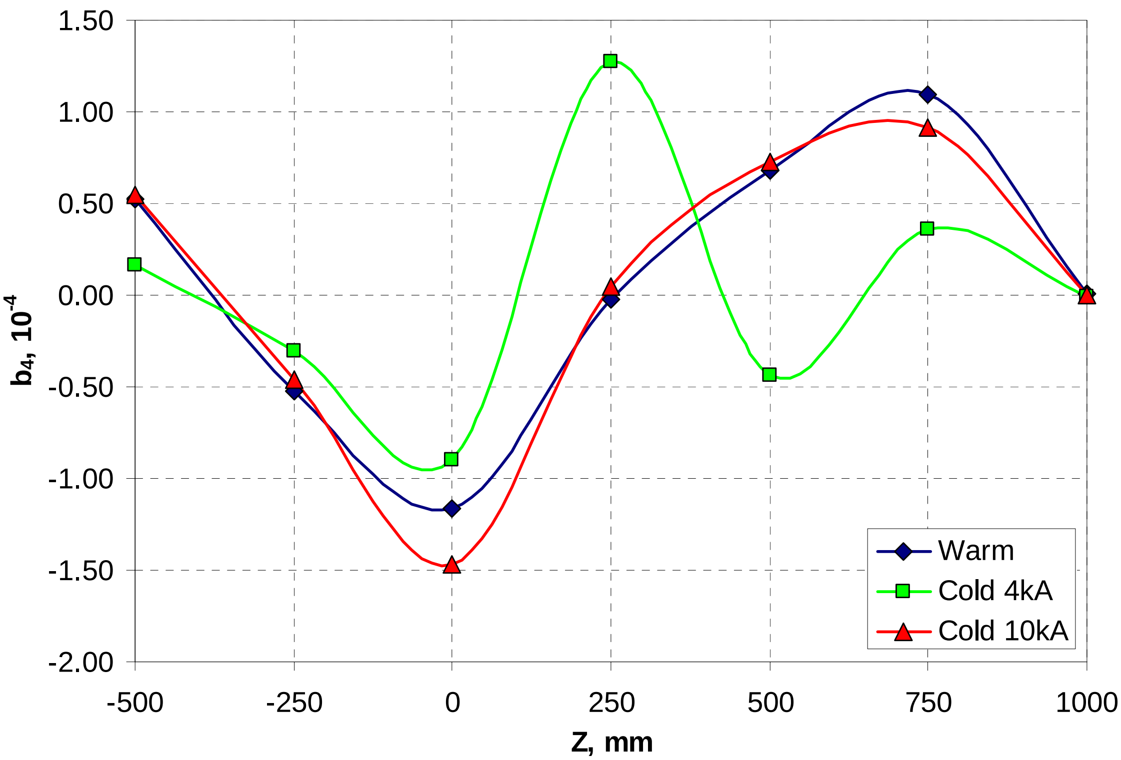

Figure 6-5. Normal octupole along Z-axis.

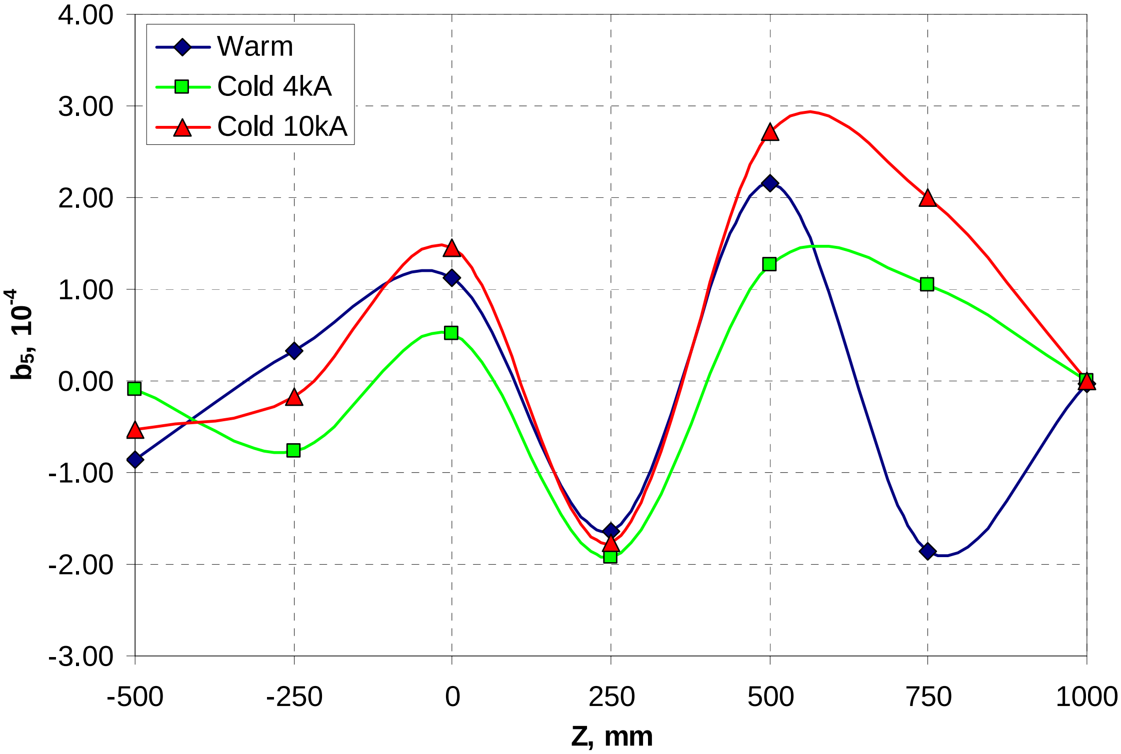

Figure 6-6. Normal decapole along Z-axis.

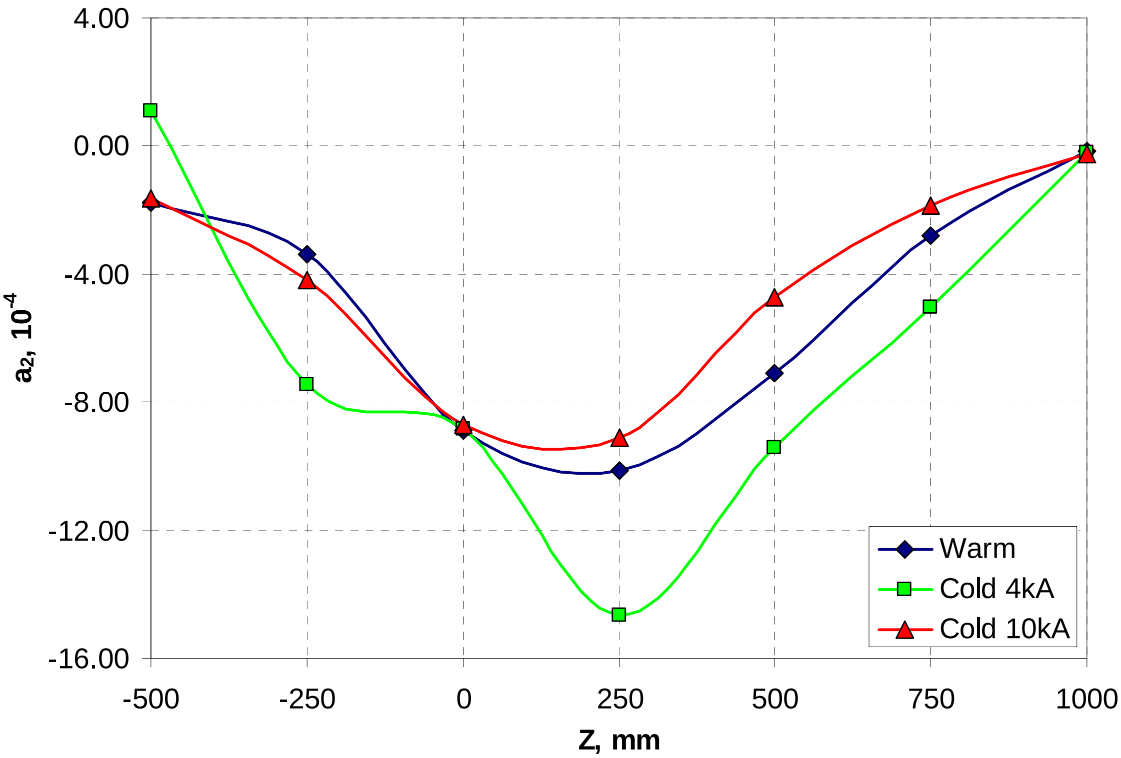

Figure 6-7. Skew quadrupole along Z-axis.

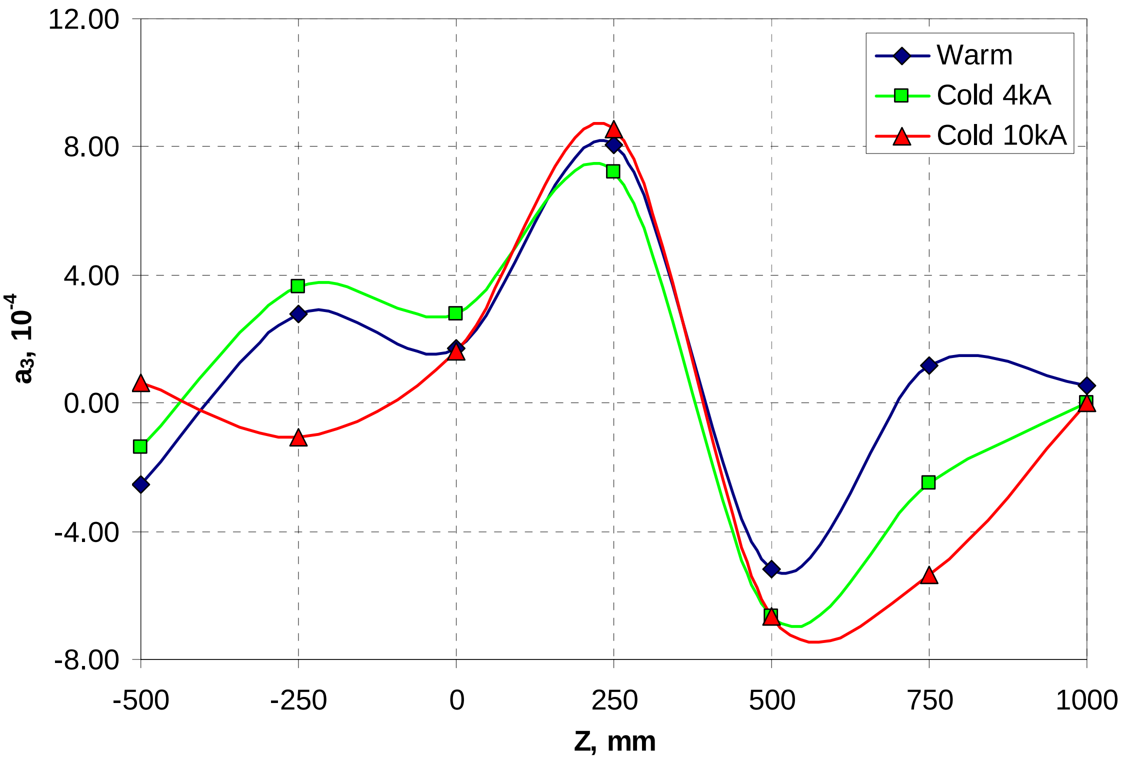

Figure 6-8. Skew sextupole along Z-axis.

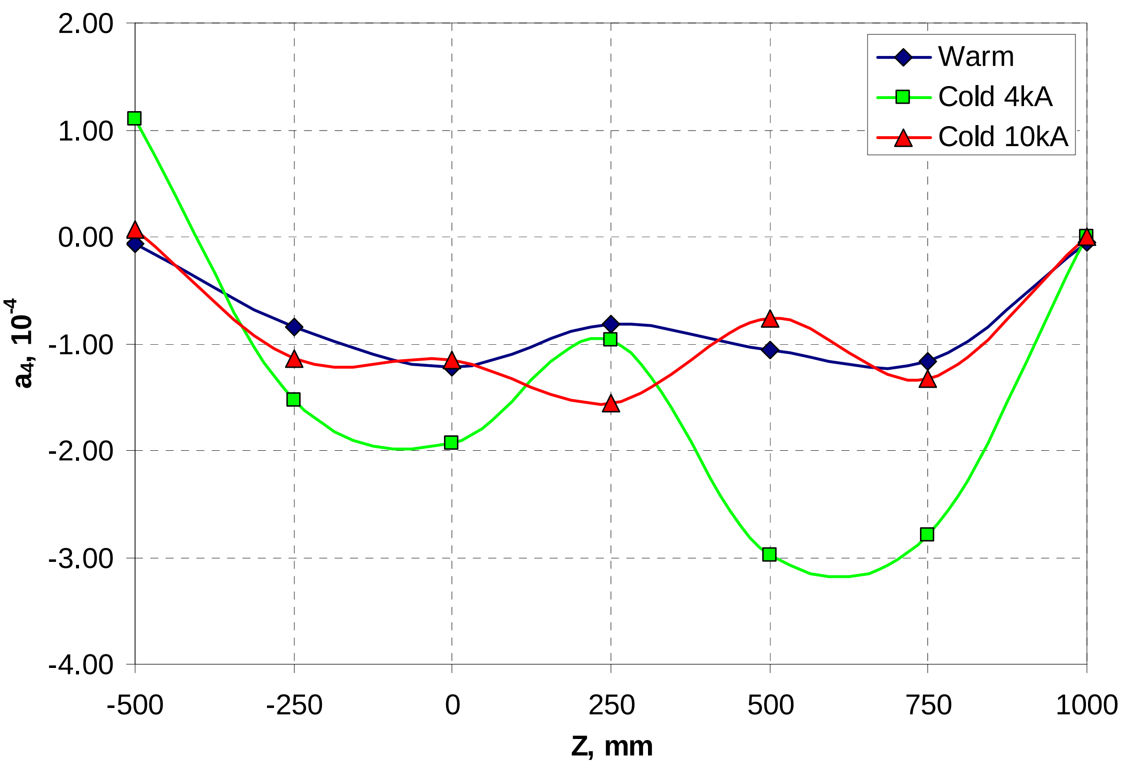

Figure 6-9. Skew octupole along Z-axis.

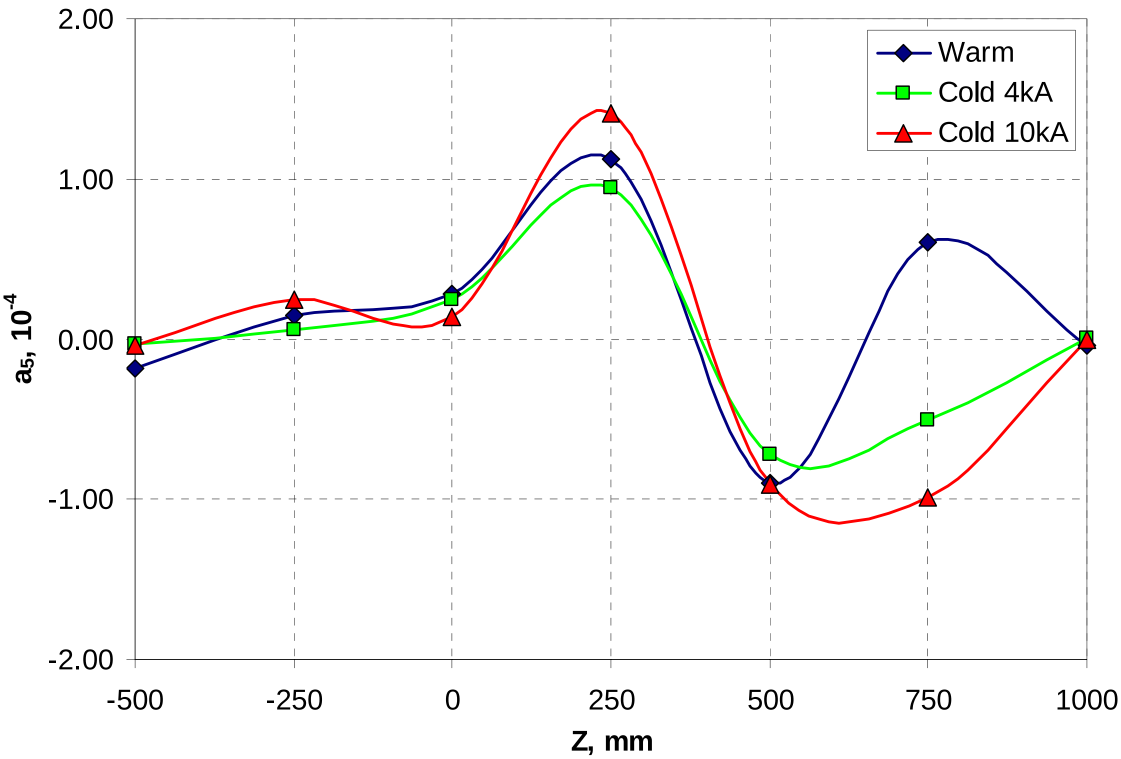

Figure 6-10. Skew decapole along Z-axis.

Hysteresys loops

The loop measurements were performed in two consecutive cycles up to 16000 A with the ramp rate 20 A/s; up to 15000 A with the ramp rate 40A/s; and up to 13000 A with the ramp rate 80 A/s. There was observed an abnormal inversed behavior in harmonics (similar to HFDA05), possibly attributed to large interstrand coupling currents in the cable. Figure 6-11 to Figure 6-14 present the normal and skew quadrupole and sextupole components in the second cycles as functions of the main field component. A stair-step measurement was performed in order to acquire more data on this effect.

Stair-step measurement

The current was gradually ramped up to 16000 A with 2000 A steps and then ramped down in the similar way. The ramp rate was 20 A/s and the dwell time at each step was 60 seconds. Figure 6-15 shows the sextupole harmonic as a function of field and Figure 6-16 shows sextupole harmonic and current as functions of time. From Figure 6-17 presenting a typical stair-step one can see that the ramp-induced sextupole relaxation time is ~40 s (similar to HFDA05), however there is no visible slower decay after the relaxation.

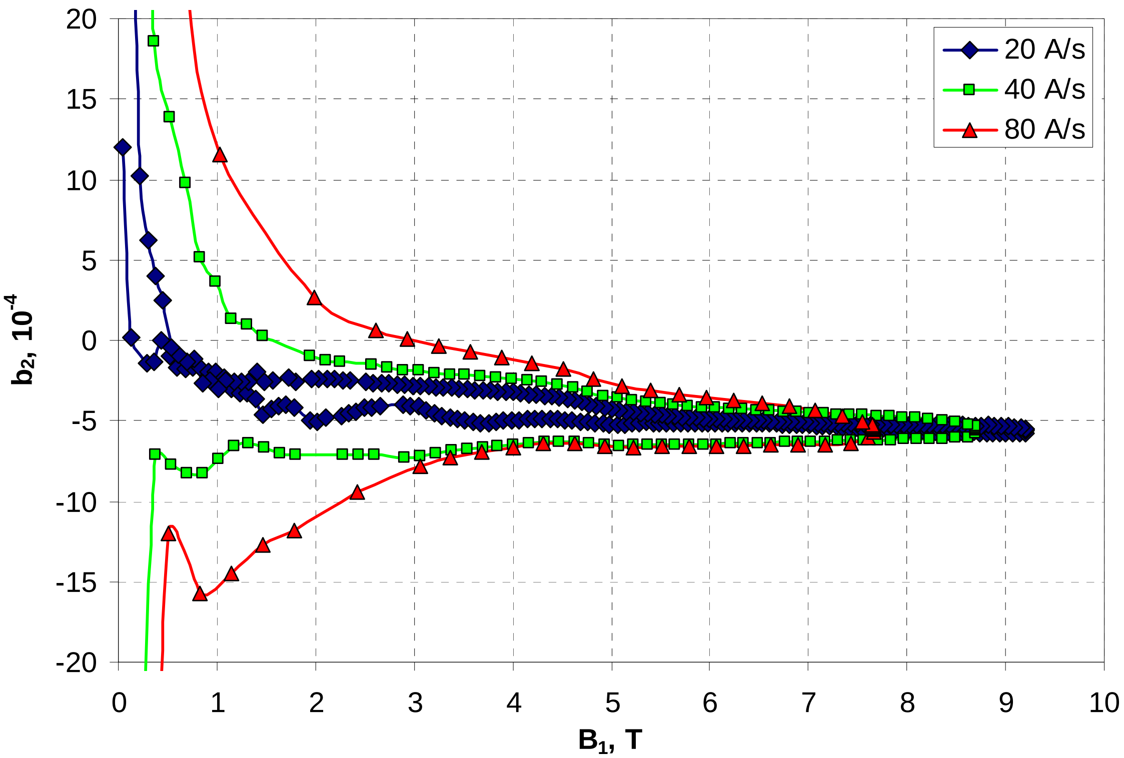

Figure 6-11. Normal quadrupole loops.

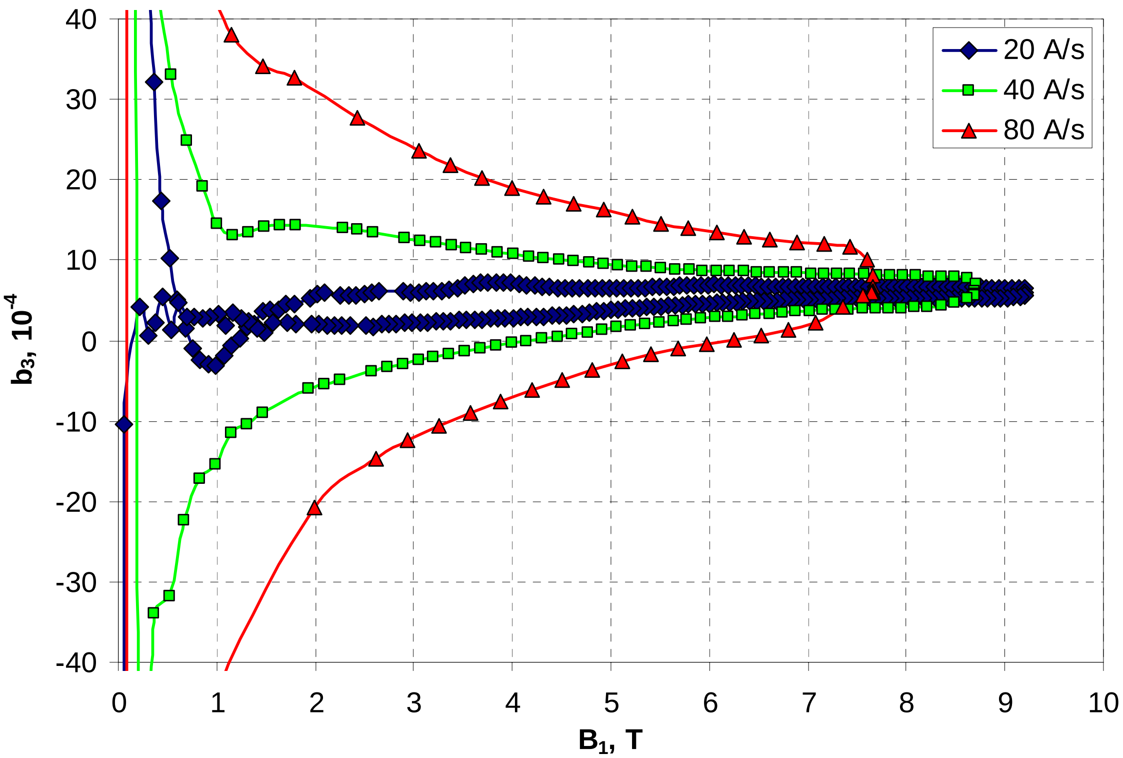

Figure 6-12. Normal sextupole loops.

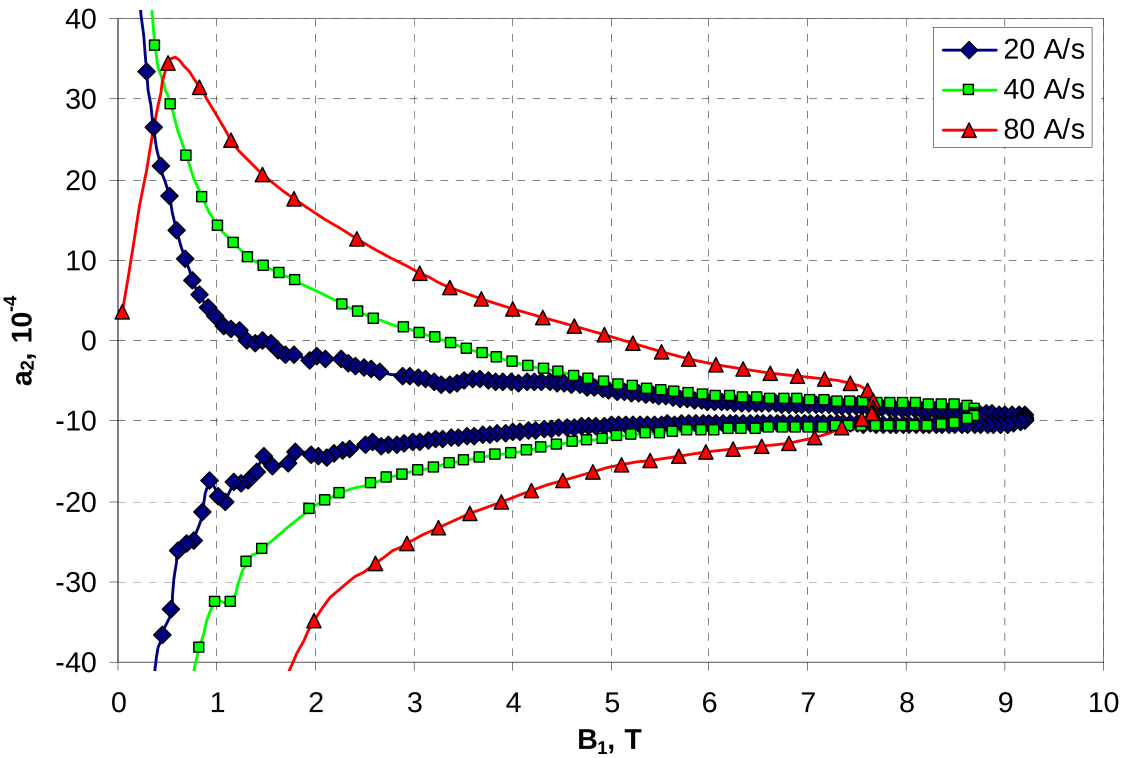

Figure 6-13. Skew quadrupole loops.

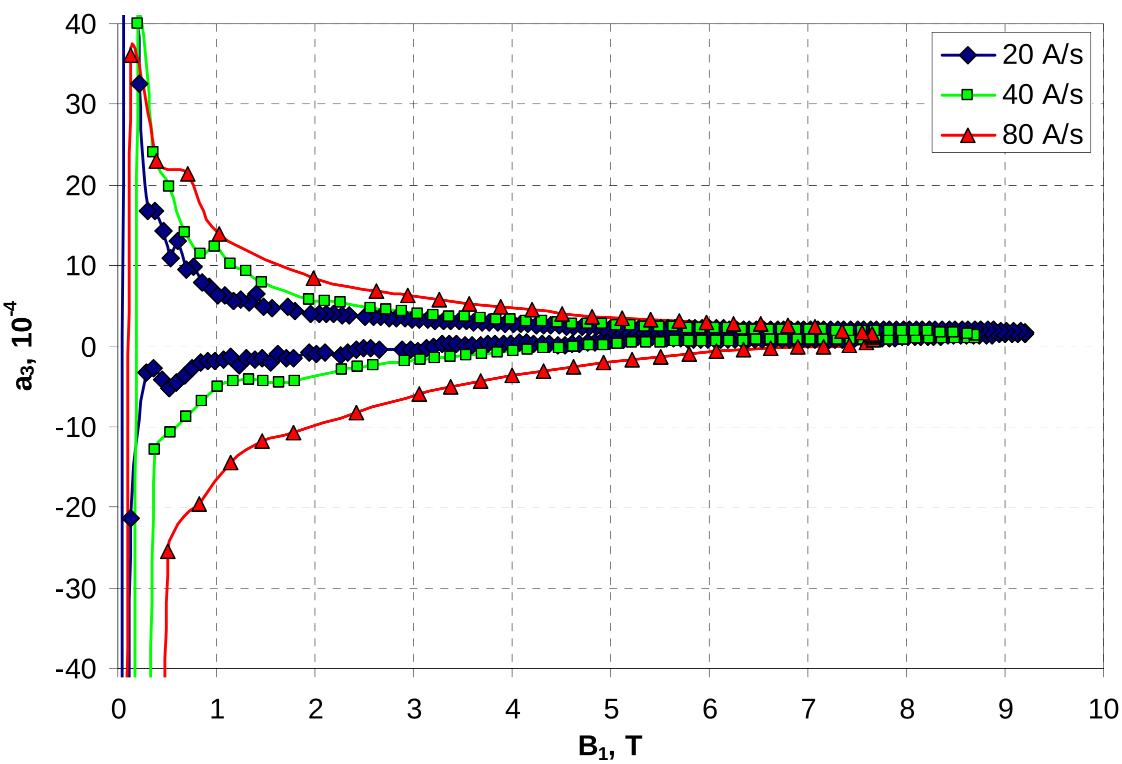

Figure 6-14. Skew sextupole loops.

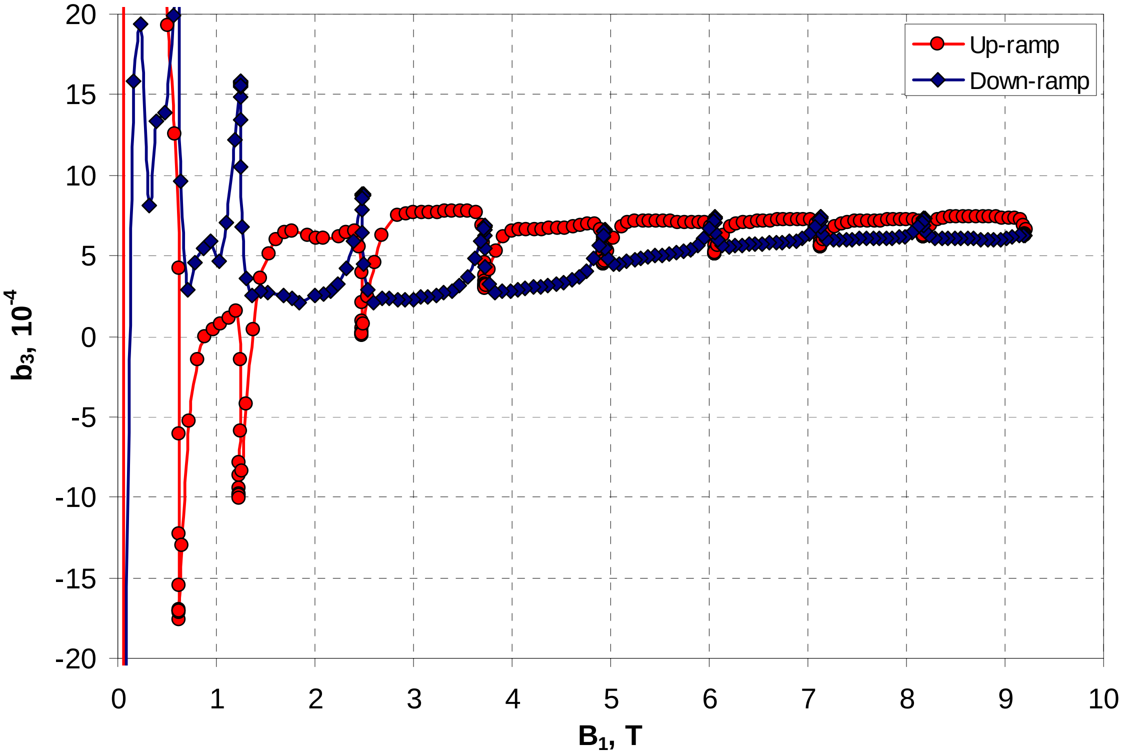

Figure 6-15. Sextupole as a function of field.

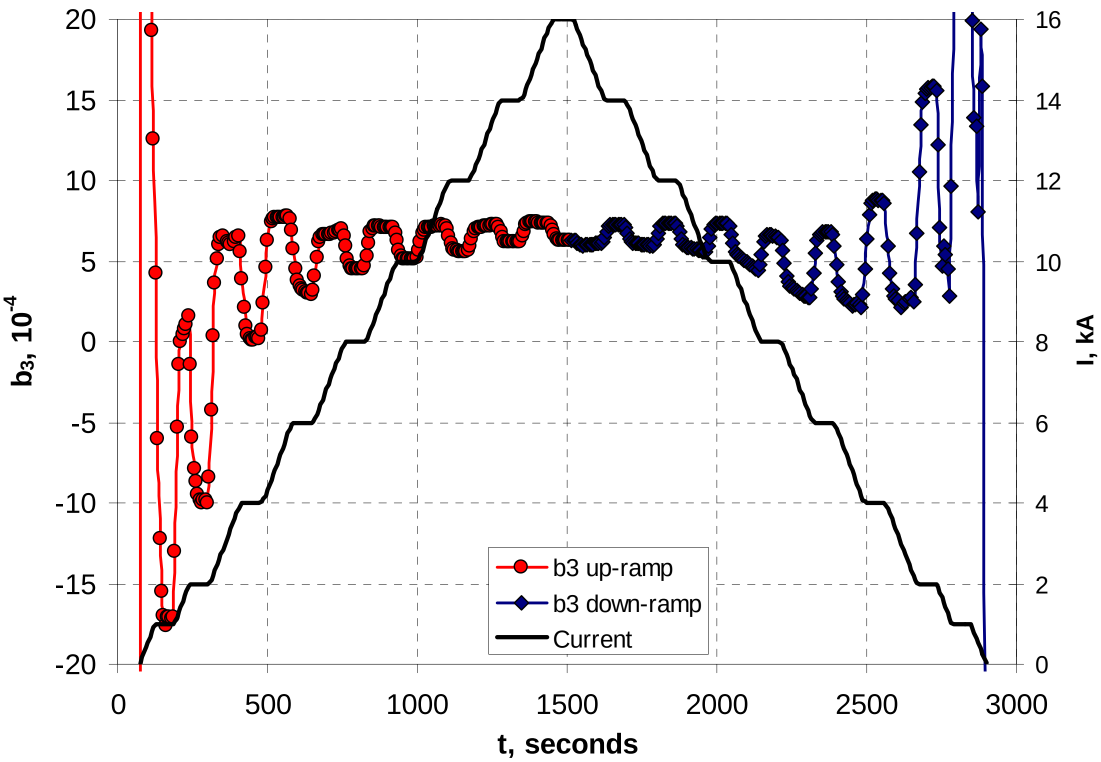

Figure 6-16. Sextupole and current as functions of time.

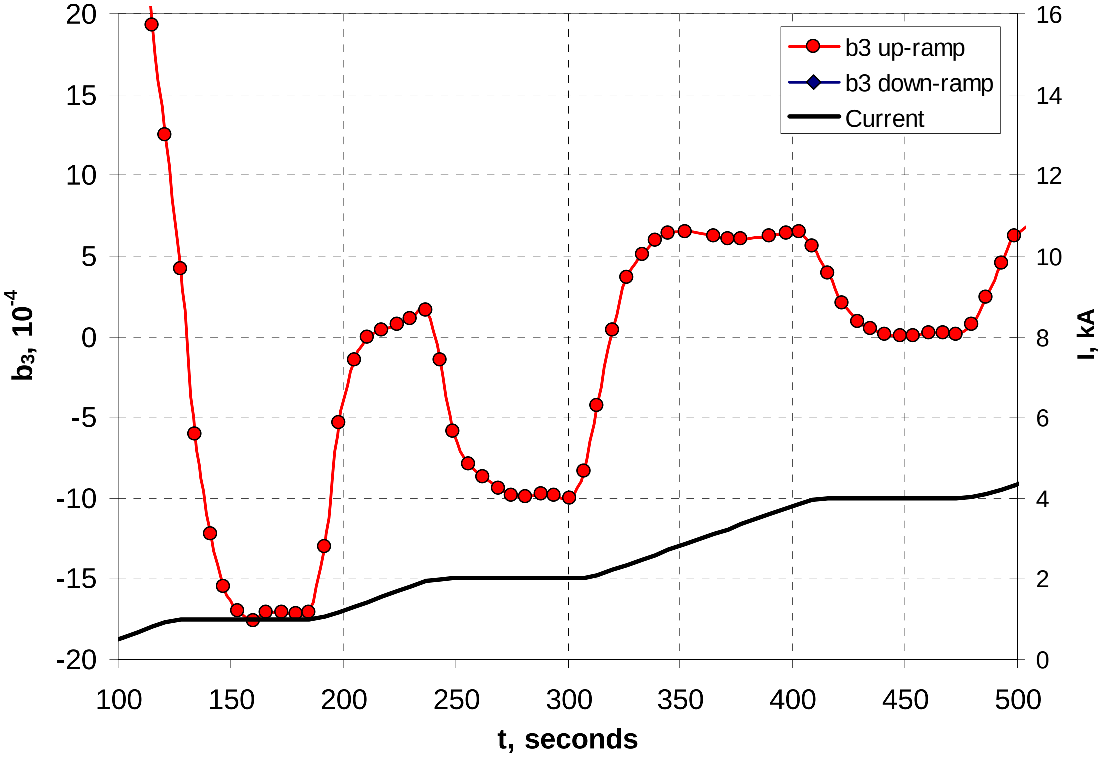

Figure 6-17. Sextupole and current as functions of time.

Accelerator profile (snap-back) measurements

Long-term harmonic decay and snap-back were measured during 30 minutes at 4400 A plateau following the pre-cycle up to 16000 A. Figure 6-18 shows the sextupole and current profiles during the whole measurement and Figure 6-19 presents the sextupole and current at the 30 minutes plateau. The sextupole behavior was completely different from HFDA05 magnet. There was no large long-term decay. Instead, the average harmonic value changed by only ~0.5 units during the 30 minutes. However, there were aperiodic oscillations with ~0.5 unit amplitude around the average value during the first 10 minutes at the plateau that then changed into a slowly changing periodic pattern for the rest of the plateau.

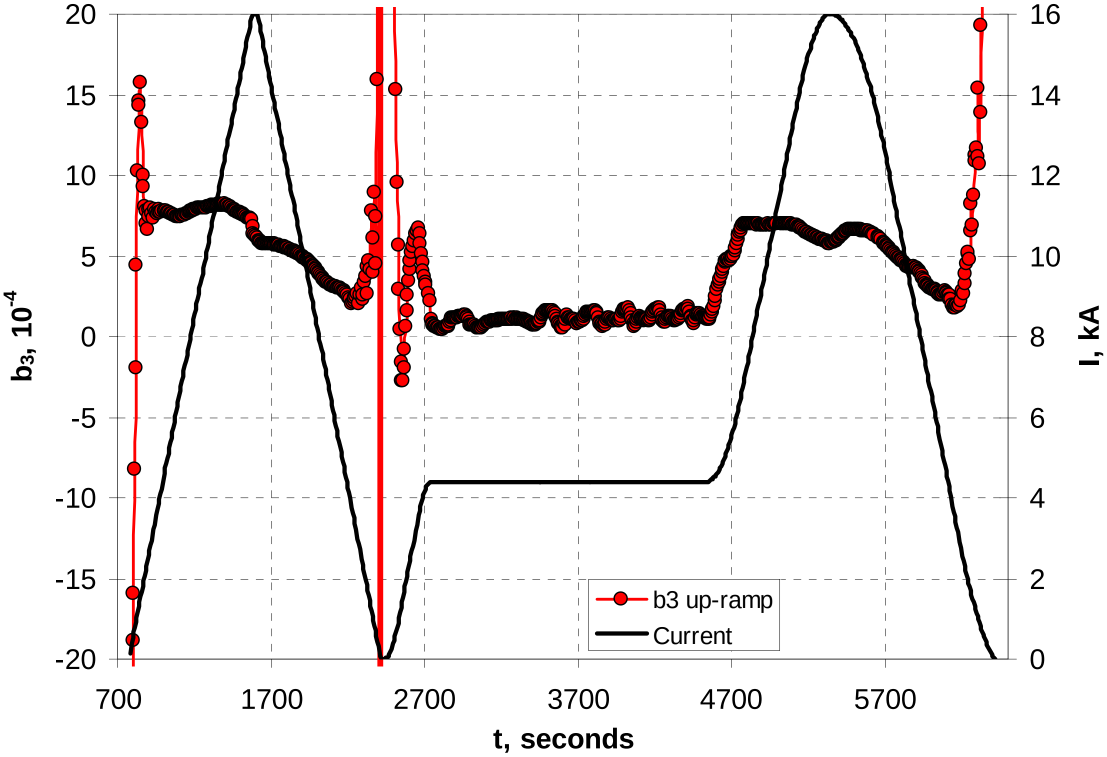

Figure 6-18. Sextupole and current as functions of time.

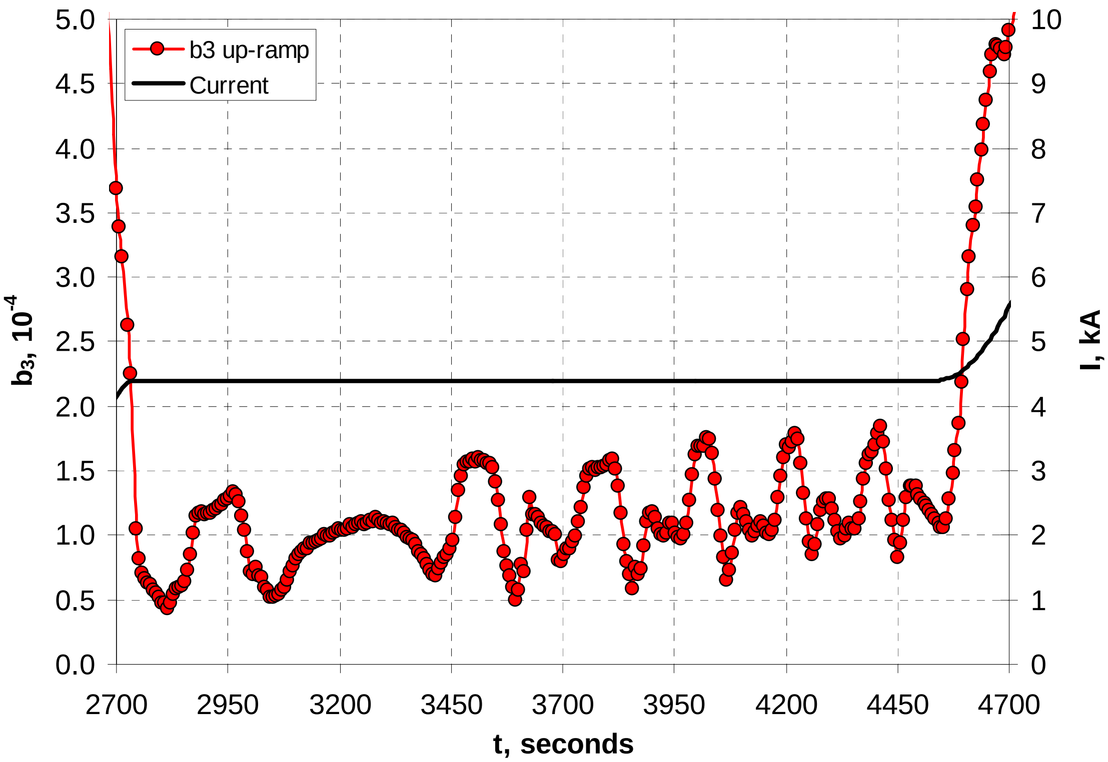

Figure 6-19. Sextupole and current as functions of time.

7. AC loss measurement

Energy Loss measurements were performed on HFDA06 at 4.5K using two HP3458A Digital Multimeters (dmm) setup to integrate over 1 power line cycle and sample at 60Hz. One dmm measured the magnet voltage and the second dmm measured the magnet current via the power system current transductor. The magnet was ramped between 500A and 6500A for all measurements. Three measurements were performed at each ramp rate of 25A/s, 100A/s, and 150A/s, and three pre-ramp cycles were performed magnet conditioning.

The measured **Hysteresis = 224+/-51 Joules**
And the measured **Slope = 8.0+/-0.5J/A/s**

The following is a plot of the data:

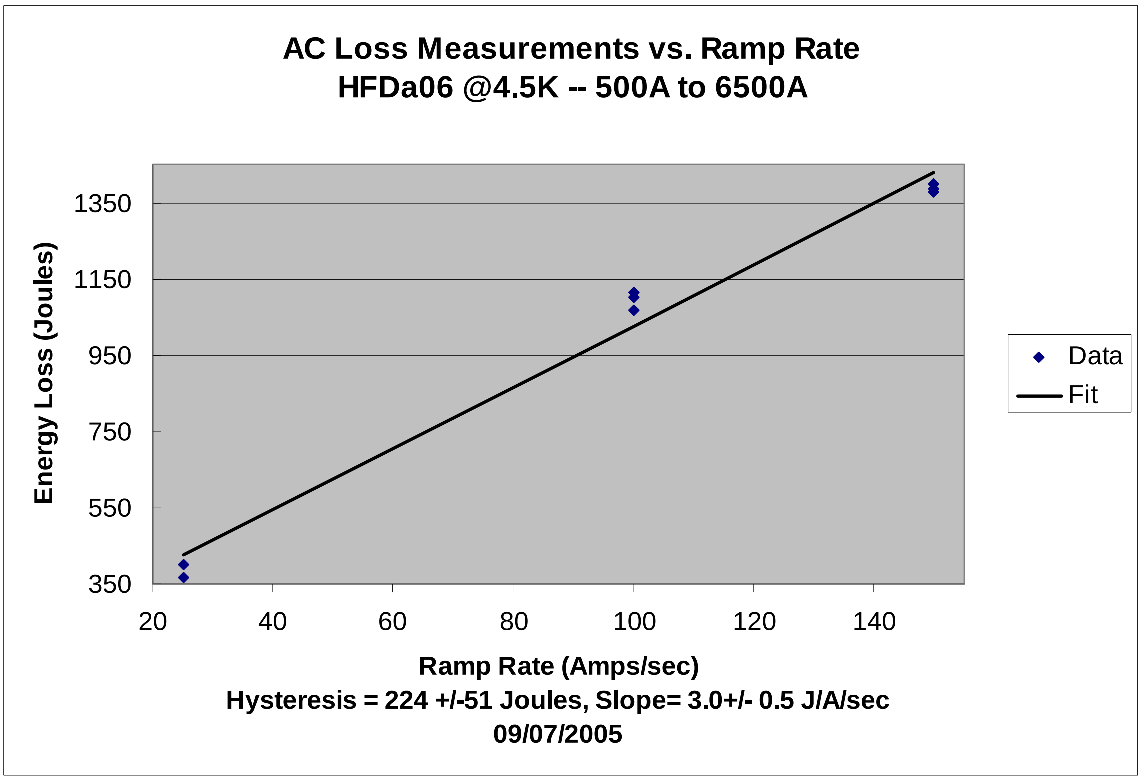

Figure 7-1. AC loss measurement plot as a function of current ramp rate.

Table 7-1.

HFDa06 Energy Loss Measurement Summery @4.5K -- 500Amps to 6500Amps

Ramp Rate(Amps/sec)	*Energy Loss(Joules)*	*Integral Volts*
25	368	0.45
25	399	-0.74
100	1103	0.005
100	1113	0.009
100	1068	0.001
150	1379	0.02
150	1385	0.021
150	1397	0.038

8. RRR measurement

The RRR measurement was performed on 9/26 – 10/02. The magnet was gradually warming up and meanwhile we recorded the half coil voltage values generated by 10 A across the magnet (see Fig. 8-1). The measured RRR values are H1= 152 ±5, H2=140 ±5.

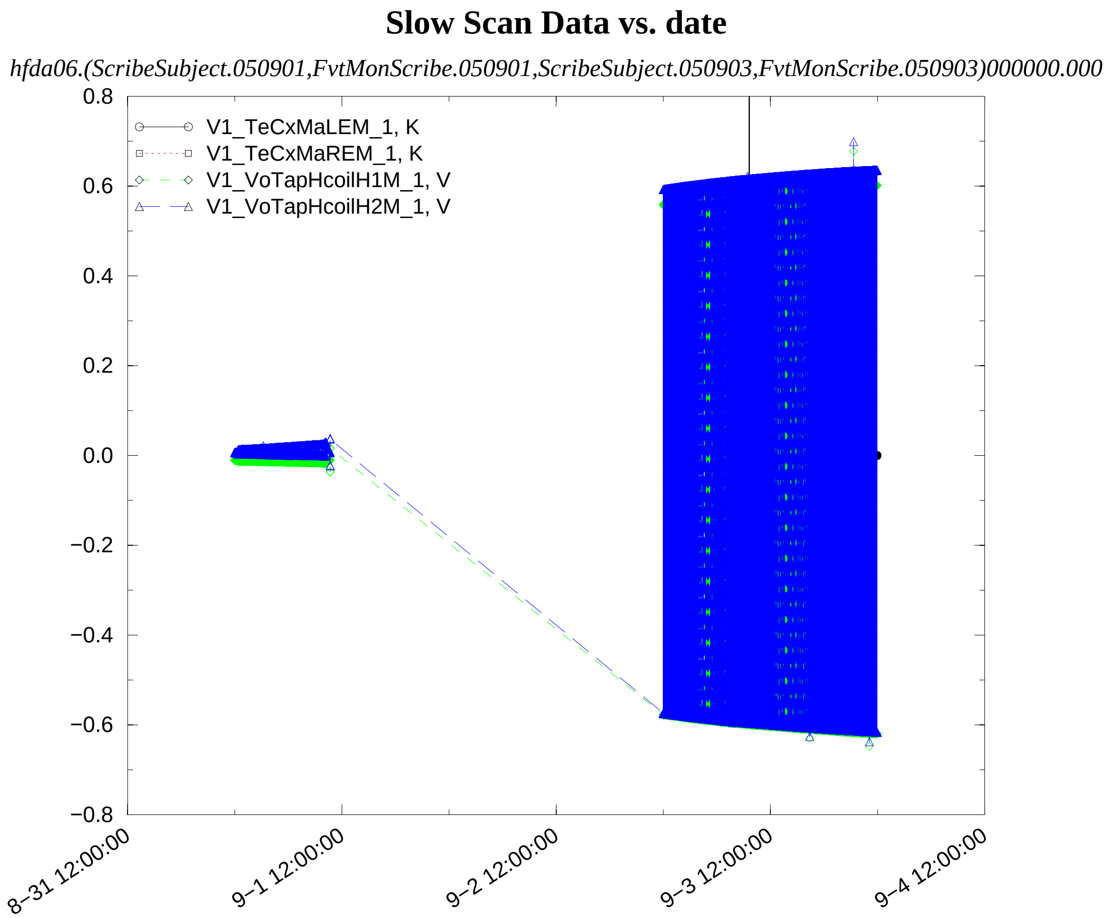

Figure 8-1. Magnet voltage is measured at applied current of 10 A as a function of time.

9. Strip Heater Studies

We performed strip heater studies. The heaters were connected in parallel. Voltage vs. time delay studies are summarized in Fig. 9-1. This heater is quite effective for the entire current range if the Heater firing unit voltage is set to 400V.

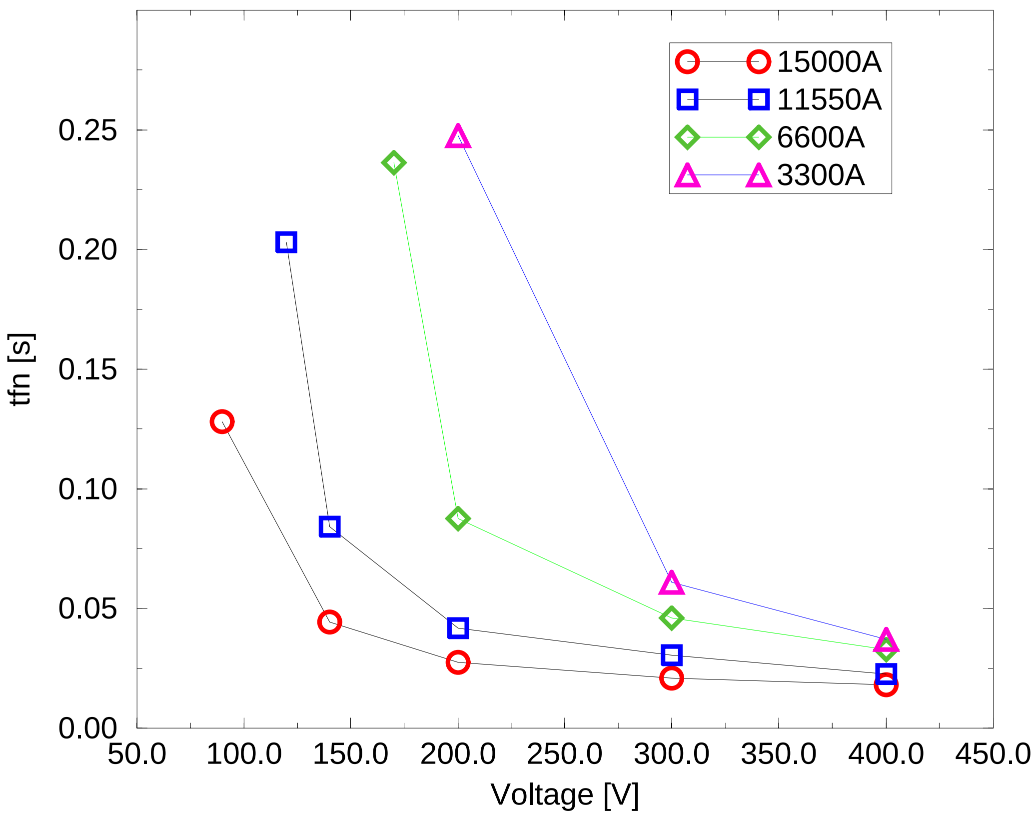

Fig. 9-1. Strip heater voltage versus time delay is plotted.

We also performed quench integral studies.

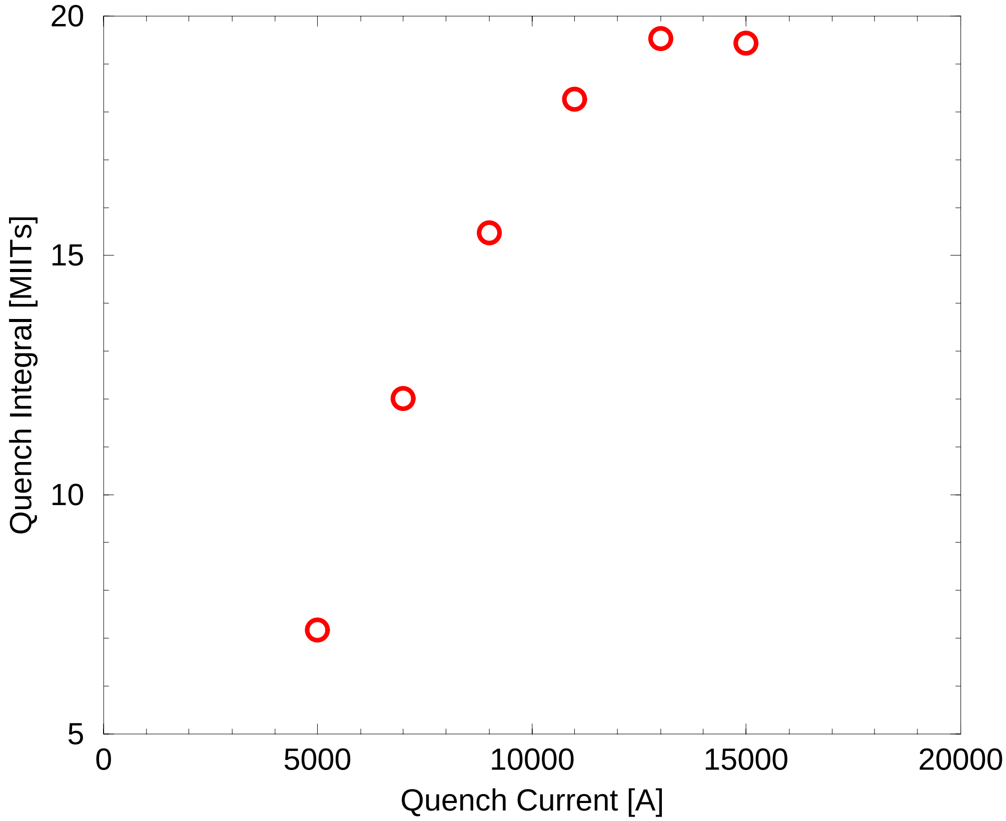

Fig. 9-2. Quench Integral as a function of quench current is plotted.