TS-SSC-91-249
12/18/91

MEASUREMENTS OF AC LOSSES IN LONG 50mm SSC COLLIDER DIPOLE MAGNETS AT FERMILAB

Joe Ozelis

Fermi National Accelerator Laboratory
Batavia, Illinois

Introduction

Measurements of the AC losses under a unipolar ramp cycle were performed on magnets DCA311 and DCA312, full-size 50mm collider dipole magnets constructed at Fermilab. The loss measurements were obtained using the digital integration technique developed for short model magnets. This represents the first instance of AC loss measurements being performed on long SSC magnets, the results of which are described below.

Magnet DCA311

AC loss measurements were performed on magnet DCA311 using the standard unipolar ramp, from 500A to 5000 A then back to 500A, with 5 second dwells at I_{min} and I_{max}. Because this magnet showed a rather strong quench current dependance with ramp rate (see Figure 1), it could not be tested at the higher ramp rates customarily used with short model dipoles. Therefore, AC loss measurements were performed at ramp rates of 30, 50, 75, 100, 125, and 150 A/sec. Unlike the measurement procedure for short magnets, two power supplies were used rather than one, owing to the difficulty in re-configuring the test setup. (Normally, one power supply is used in this measurement, in order to eliminate effects caused by non-uniform current output of two supplies in parallel.) No deleterious effects from using two supplies were observed in the raw data, leading to the conclusion that the regulation and uniformity of the power supply system used for the long magnets is superior to that used with the short magnets; hence, operation with both supplies is indeed acceptable for these measurements. Another difference between this measurement and measurements on short magnets was that the current was measured using the output of the Holec current transducer, rather than a shunt. This provided a stronger, cleaner signal, that was immune to shunt self-heating effects. Apart from these differences, all other parameters of the measurement runs were identical to those used during measurements on short magnets.

The magnet was typically set up to do a series of 12-14 ramp cycles at a given ramp rate, with data taken on the 4th and subsequent cycles. The data from the unipolar ramp rate study is shown in Table I and plotted in Figure 2. The linear fit to the data yields a hysteresis loss of about 614 Joules, and an eddy current dependance of 15.7 Joules/A/sec. This is to be compared with 109 Joules and 0.70 Joules/A/sec., respectively, for a short 50mm dipole magnet (DSA324). The results for both DCA311 and DSA324 are plotted together in Figure 3. The hysteresis loss has increased by a factor of about 6, surprisingly low, as we expect the hysteresis loss to scale with volume of superconductor, and, hence, length. The ratio of the lengths of the straight sections of the long coil/short coil is 11.7, for reference. The difference might be due to differences in the superconducting cable itself, vis a vis filament size, number of strands, J_c, etc. The eddy current behavior has increased by a factor of about 22, nearly double the value expected from a simple length scaling. This possibly results from differences in intra-strand resistance between the cable used in magnet DCA311 and magnet DSA324. At any rate, the very high eddy current losses correlate well in a qualitative manner with the degraded ramp rate performance of magnet DCA311.

Magnet DCA312

Magnet DCA312 was tested in essentially the same manner as magnet DCA311, except that several additional ramp rates were employed. This resulted from magnet 312's rather poor ramp rate performance (see Figure 4), which precluded using ramp rates above 100 A/sec. Additional drive tables at lower ramp rates were again needed. The magnet was finally tested at ramp rates of 30, 40, 50, 60, 75, and 90 A/sec. The data can be found in Table I and are plotted in Figure 5. It is immediately obvious that magnet DCA312 has exceedingly high AC losses; both hysteresis losses and eddy current losses are the highest yet seen. The hysteresis loss for magnet DCA312 is 1393 Joules, more than twice that of magnet DCA311, and about 12.8 times that of magnet DSA324. In this regard, magnet DCA312 more closely agrees with the hysteresis loss we would expect by scaling the short magnet results by magnet length (12.8 vs 11.7). The eddy current dependence of magnet DCA312 is much more striking when compared to previous 50mm results - the ramp rate dependence of magnet DCA312, at 55.4 Joules/A/sec., is 3.5 times as large as for magnet DCA311, and almost 80 times as large as the short magnet (DSA324) result ! This is evidently related to the magnet's quench performance at high ramp rates, eddy current heating being the culprit responsible for quench current degradation. At present, no concrete explanation for the high eddy current losses in magnet DCA312 can be offered from this data, although low intra-strand resistance is suspected. Strand-to strand resistance and AC loss measurements performed on cable samples used in the winding of coils for these magnets may provide an additional source of enlightenment.

Conclusions

The AC losses experienced during a standard unipolar ramp cycle have been measured for two full-size 50mm bore SSC collider dipole magnets. The results from these measurements agree well with our expectations, both from simple scaling of short magnet results, and from observations of quench current degradation with ramp rate. We find a strong correlation between the eddy current heating as measured in an AC loss measurement, and the degree of degradation of quench current with increasing ramp rate. No correlation between the amount of hysteresis (magnetization) loss and other magnet performance indicators can be drawn from he present work, however the hysteresis loss should be correlatable to the time decay of the remnant sextupole, for example. This might prove to be worthy of further investigation.

Acknowledgements

The assistance of the members of the Fermilab Magnet Test Facility (MTF) in performing these measurements is gratefully acknowledged, in particular the efforts of Joe DiMarco, Joseph Kuzminski, and Darryl Orris.

TABLE I

AC LOSS DATA FOR MAGNETS DCA311, DCA312, AND DSA324

Ramp Rate (A/sec)	DCA311	DCA312	DSA324
30	1499	3678	121
30	1105	3150	130
40	----	3256	----
40	----	3535	----
50	1334	4012	151
50	1262	4008	156
60	----	4481	----
60	----	4626	----
75	1695	5586	----
75	1450	5531	----
90	----	6652	----
90	----	6427	----
100	2186	----	164
100	2184	----	184
125	2625	----	----
150	3072	----	218
150	3031	----	208
200	----	----	239
200	----	----	254
200	----	----	245
250	----	----	300
250	----	----	282
300	----	----	325
300	----	----	313
	\------------	Loss/Cycle (J)	------------/

	DCA311	DCA312	DSA324
Eddy Current Dependence (J/A/sec)	15.7	55.4	0.7
Hysteresis Loss (J)	614	1393	109

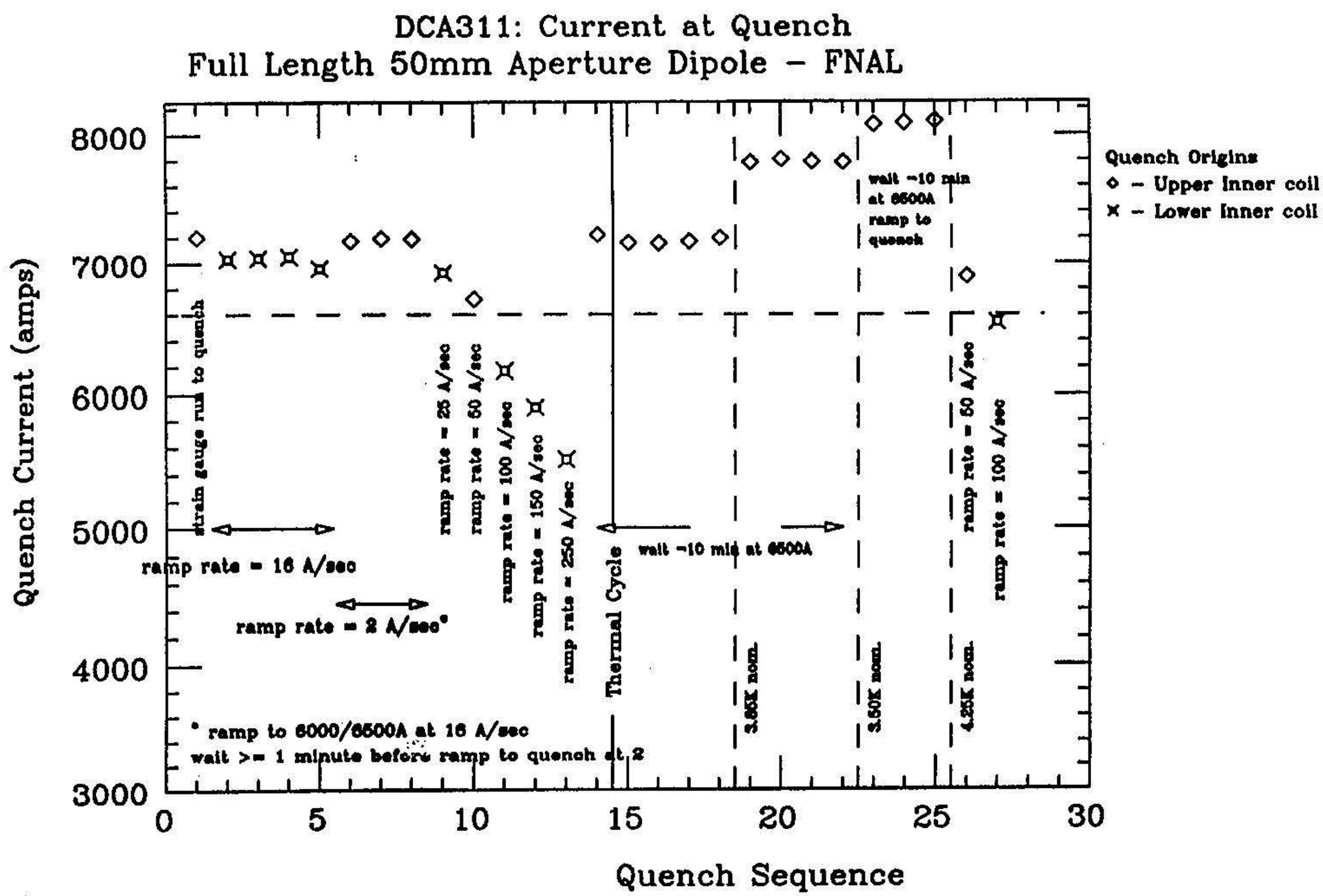
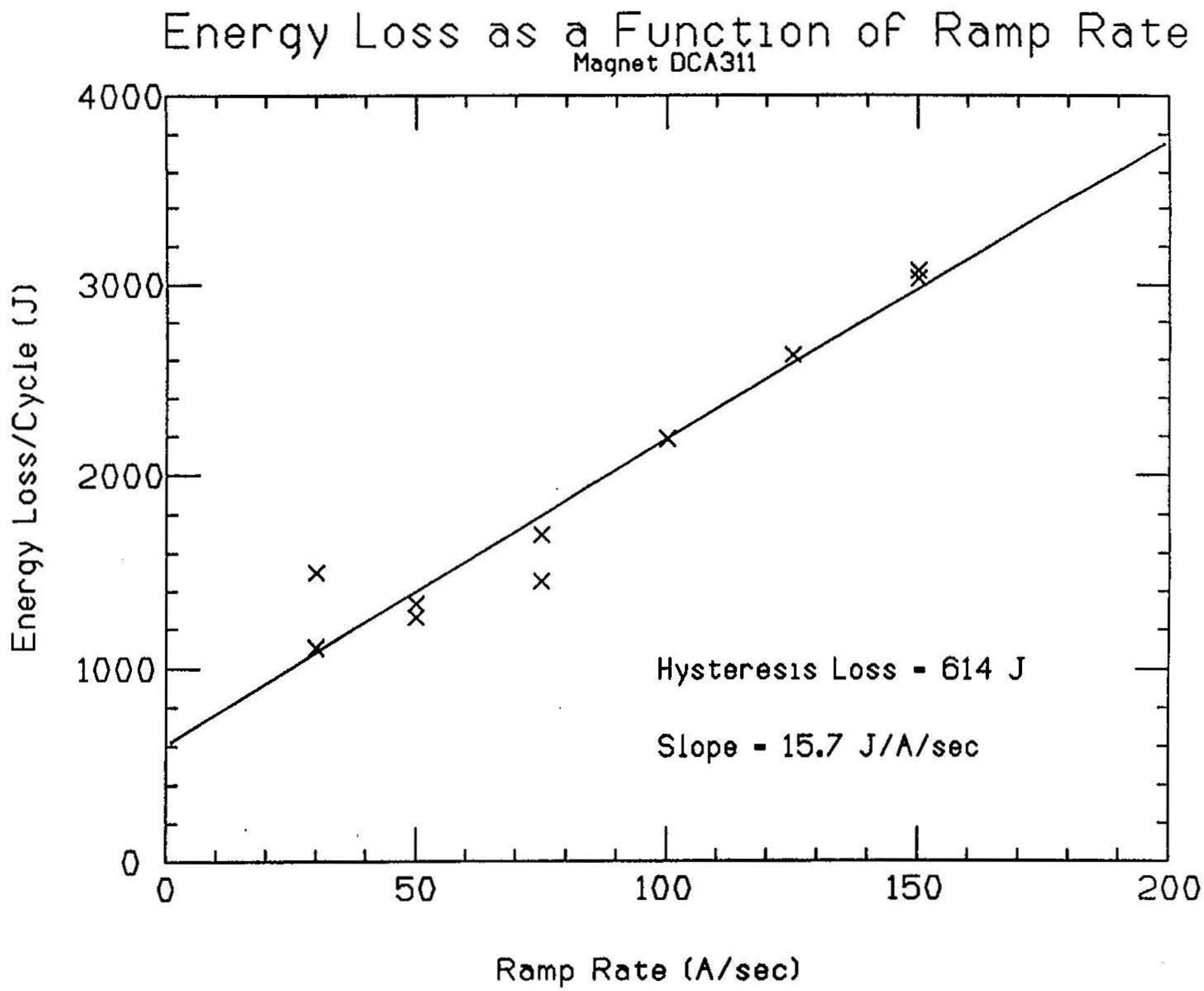

DCA311: Current at Quench
Full Length 50mm Aperture Dipole - FNAL
Quench Current (amps)
Quench Sequence
Quench Origins
◇ - Upper Inner coil
ⵋ - Lower Inner coil
strain gauge run to quench
ramp rate = 16 A/sec
ramp rate = 2 A/sec*
ramp rate = 25 A/sec
ramp rate = 50 A/sec
ramp rate = 100 A/sec
ramp rate = 150 A/sec
ramp rate = 250 A/sec
Thermal Cycle
wait ~10 min at 6500A
wait ~10 min at 6500A ramp to quench
3.86K nom.
3.50K nom.
4.25K nom.
ramp rate = 50 A/sec
ramp rate = 100 A/sec
* ramp to 6000/6500A at 16 A/sec
wait >= 1 minute before ramp to quench at 2

Figure 1



Energy Loss as a Function of Ramp Rate
Magnet DCA311
Energy Loss/Cycle (J)
4000
3000
2000
1000
0
0
50
100
150
200
Hysteresis Loss = 614 J
Slope = 15.7 J/A/sec
Ramp Rate (A/sec)

Figure 2

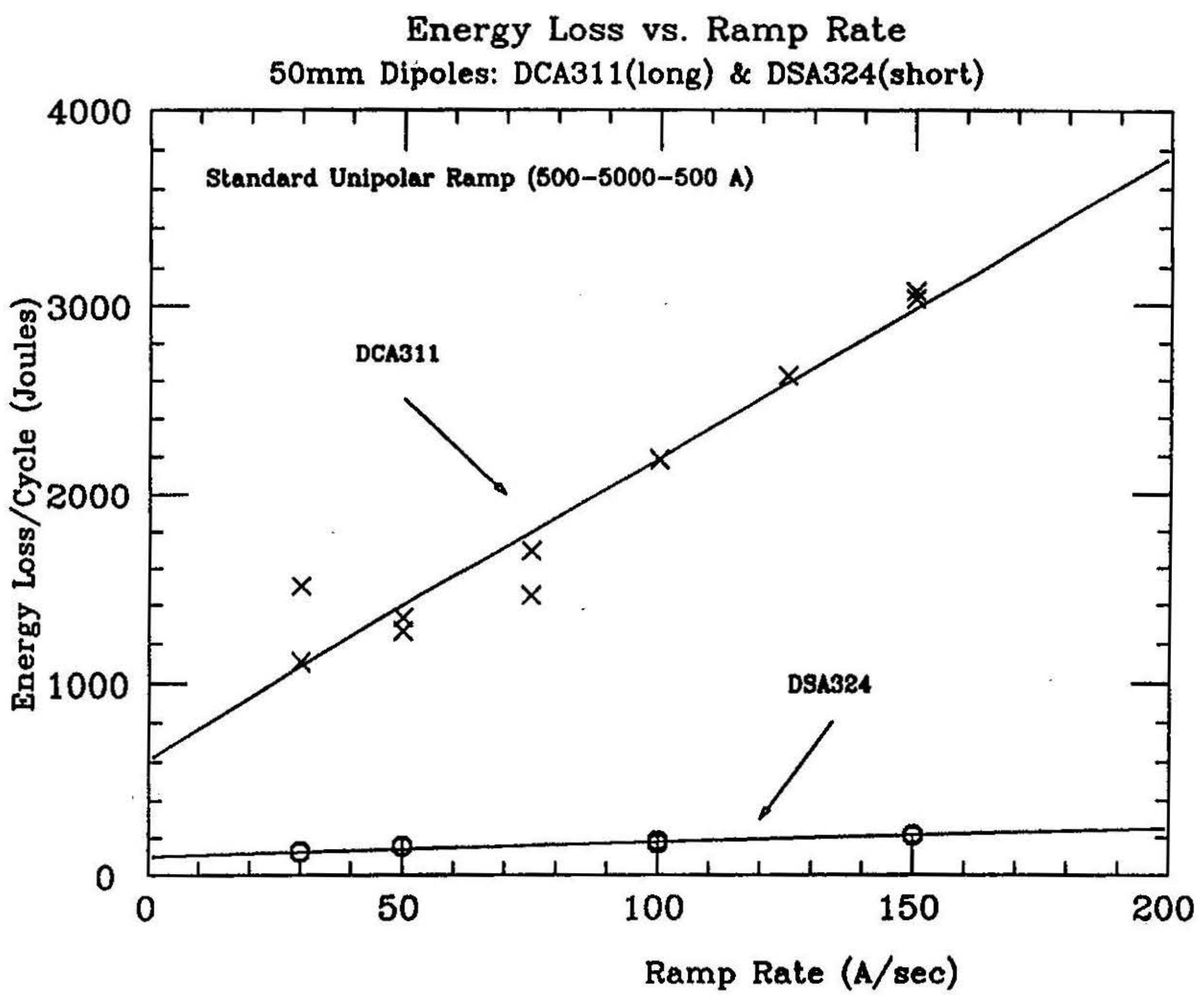
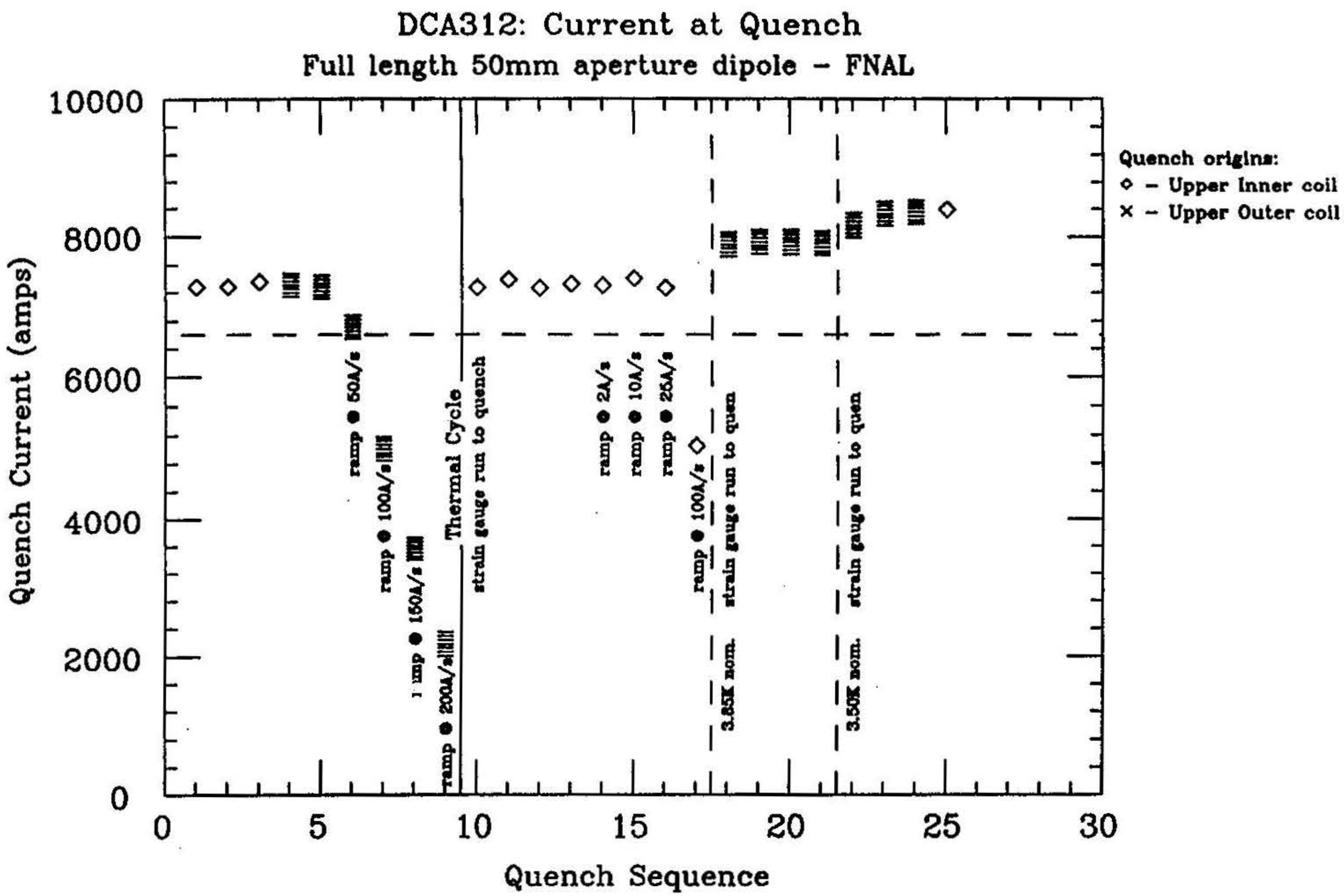

Energy Loss vs. Ramp Rate
50mm Dipoles: DCA311(long) & DSA324(short)
Standard Unipolar Ramp (500-5000-500 A)
DCA311
DSA324
Energy Loss/Cycle (Joules)
Ramp Rate (A/sec)
0
1000
2000
3000
4000
0
50
100
150
200

Figure 3



(1) - ramp to 6500A at 16 A/s
wait 10 minutes; ramp to quench at 4 A/s

Figure 4

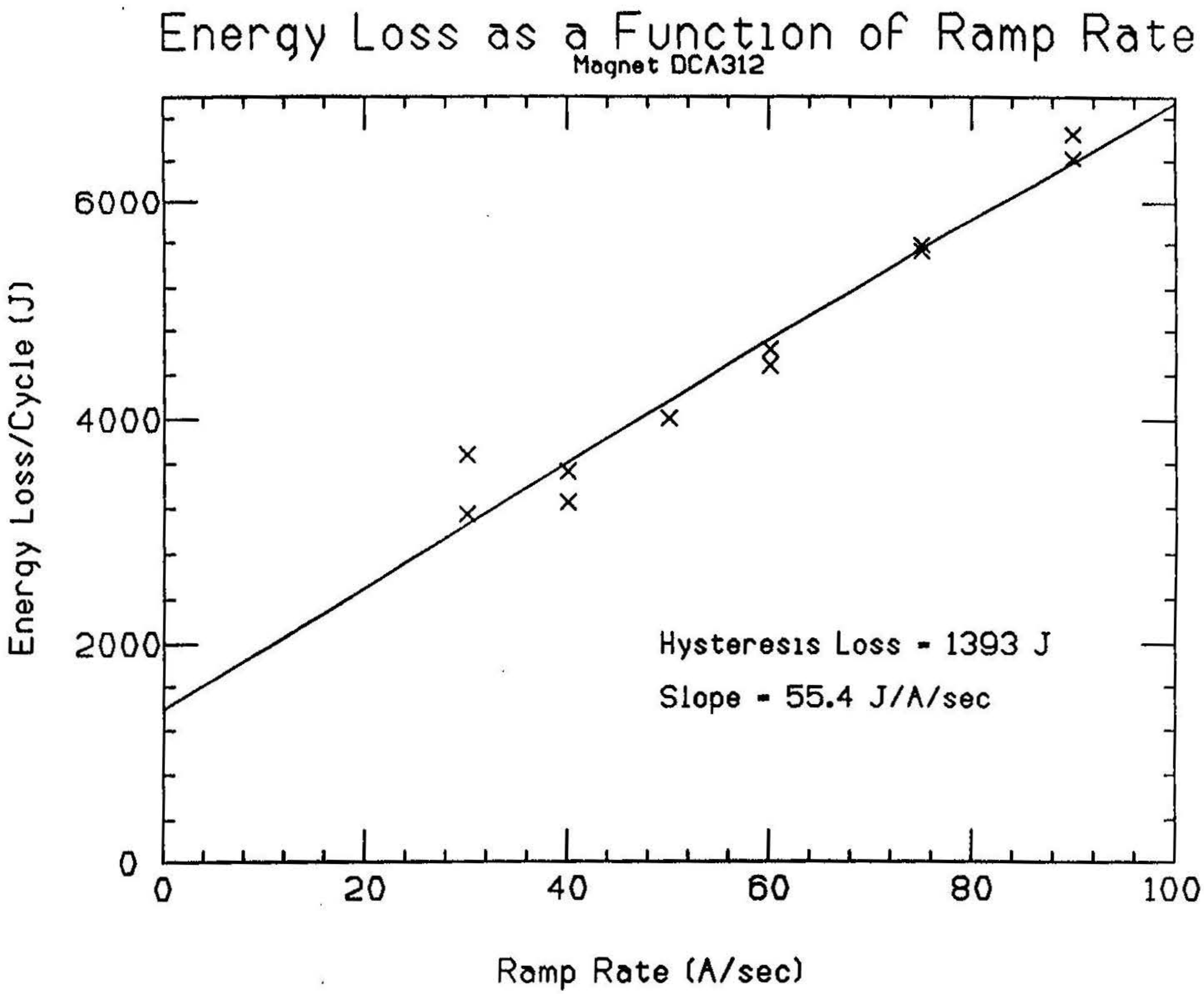

Energy Loss as a Function of Ramp Rate
Magnet DCA312
Energy Loss/Cycle (J)
0
2000
4000
6000
0
20
40
60
80
100
Ramp Rate (A/sec)
Hysteresis Loss = 1393 J
Slope = 55.4 J/A/sec

Figure 5

Distribution:

BNL
P. Wanderer

FNAL
S. Delchamps
R. Hanft
W. Koska
M. Kuchnir
M. Lamm
P. Mazur
D. Orris
G. Pewitt
J. Strait
M. Wake

SSCL at FNAL
J. DiMarco
J. Kuzminski

SSCL
R. Coombes
A. Devred
G. Snitchler
J. Tompkins