SUMMARY OF AC LOSS MEASUREMENT RESULTS FOR LONG MAGNETS AT FERMILAB

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AC loss measurements have been performed on six 15m SSC Collider dipole magnets built at Fermilab. The losses are determined by using the now-standard technique of simultaneously measuring magnet current and voltage using fast DMM's, and integrating their product over a closed current cycle. The standard current cycle is essentially a sawtooth ramp from 500 to 5000 to 500 Amps, with 5 second dwells at the maximum and minimum currents. Measurements are performed at various ramp rates from 30 to 125 Amps/sec, and are taken for two cycles at each ramp rate.

The loss per cycle is typically plotted as a function of ramp rate, A linear least-squares fit is applied to the data, yielding an intercept that can be identified as the hysteresis loss over the current cycle, and a slope that represents the eddy current heating during the current cycle. The errors of a typical measurement are on the order of 10%, and are generally largest for the low ramp rates, where the long cycle time provides a greater opportunity for noise to affect the measurement.

As eddy current heating is responsible for the degradation in quench current at high ramp rates, it is perhaps useful to try to correlate the eddy current heating (as determined from AC loss measurements) with the ramp rate dependence of the quench current of these magnets. One parameterization of the quench current degradation is the slope of the quench current/ramp rate dependence. This factor is an indication of the strength of the eddy current heating effects. For our purposes, we have calculated this slope using the values of quench current for ramp rates greater than or equal to 50 Amps/sec. At lower ramp rates, the dependence varies from a linear one quite markedly, and exhibits both positive and negative curvature, depending upon cable manufacturer. When ramp rate dependence is plotted as a function of eddy current heating, the result is a monotonically decreasing dependence that suggests a direct, linear relationship between these two parameters, as might be expected.

Analysis of the data from this set of six magnets has indicated the possibility of a systematic non-linearity in the loss/cycle versus ramp rate dependence. It appears that the slope decreases as ramp rate decreases below about 50 Amps/sec. This is especially evident in magnets DCA318 and DCA319. This non-linearity at the low ramp rates may be related to the same process or cable characteristic that accounts for the non-linearity and varying curvature in the low ramp rate sections of the quench current/ramp rate dependence.

The relevant data for these six magnets are tabulated below. Numbers in parentheses are from fits to the data where values below ramp rates of 50 Amps/sec have been excluded.

Magnet	Hysteresis Loss (J)	Eddy Current dependence (J/A/s)	Iq vs I-dot dependence (A/A/s)	Cable Manufacturer
DCA311	614 (266)	15.7 (18.5)	-5.9	Supercon

DCA312	1393 (600)	55.4 (65.1)	-30.0	IGC
DCA314	842 (752)	35.1 (36.2)	-20.4	IGC
DCA315	780 (695)	50.9 (52.0)	-25.3	IGC
DCA318	440 (47)	13.7 (17.6)	-3.4	Oxford
DCA319	445 (209)	14.8 (17.2)	-3.5	Oxford

Standard AC loss measurement cycle : 500 A to 5000 A to 500 A at various ramp rates (30 A/s ---> 125 A/s). A least-squares linear fit is applied to the loss data to yield the above figures. Quench current dependence on ramp rate is obtained by performing a least-squares linear fit to the quench current/ramp rate data for ramp rates >= 50 A/sec.

The filenames of various Topdrawer files, and a short description of the plots, are listed below. They reside in the directory USR$ROOT:[OZELIS.EIEO_DATA], and have world access.

DCA311_SU.TOP - AC loss results: ramp rate dependence, magnet DCA311

DCA312_SU.TOP - AC loss results: ramp rate dependence, magnet DCA312

DCA314_SU.TOP - AC loss results: ramp rate dependence, magnet DCA314

DCA315_SU.TOP - AC loss results: ramp rate dependence, magnet DCA315

DCA318_SU.TOP - AC loss results: ramp rate dependence, magnet DCA318

DCA319_SU.TOP - AC loss results: ramp rate dependence, magnet DCA319

(Note : The solid lines in the six plots above are fits using all of the data, while the dashed lines are fits using only data whose values of I-dot are >= 50 Amps/sec.)

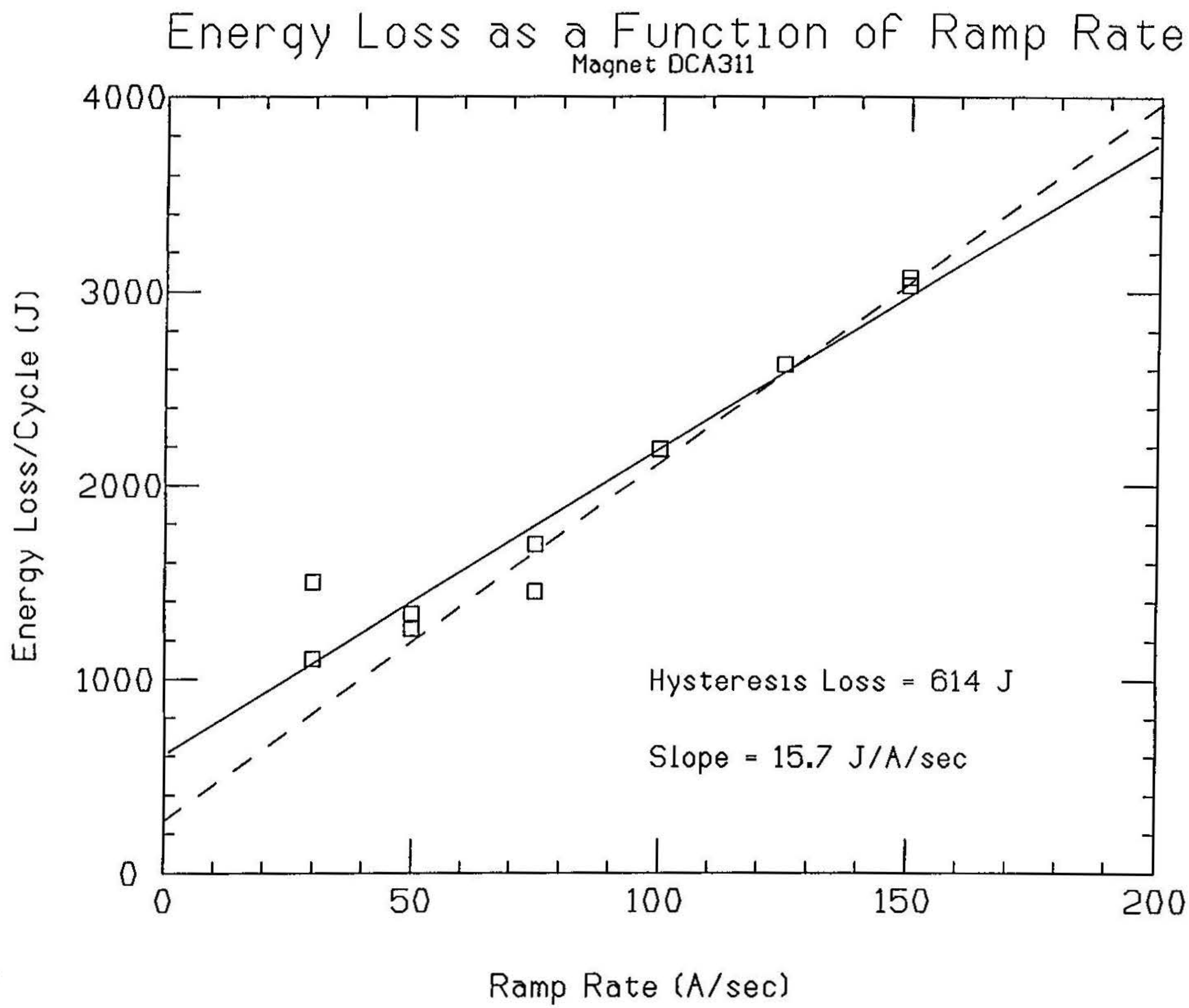
6LONG_SU.TOP - " " , all six magnets

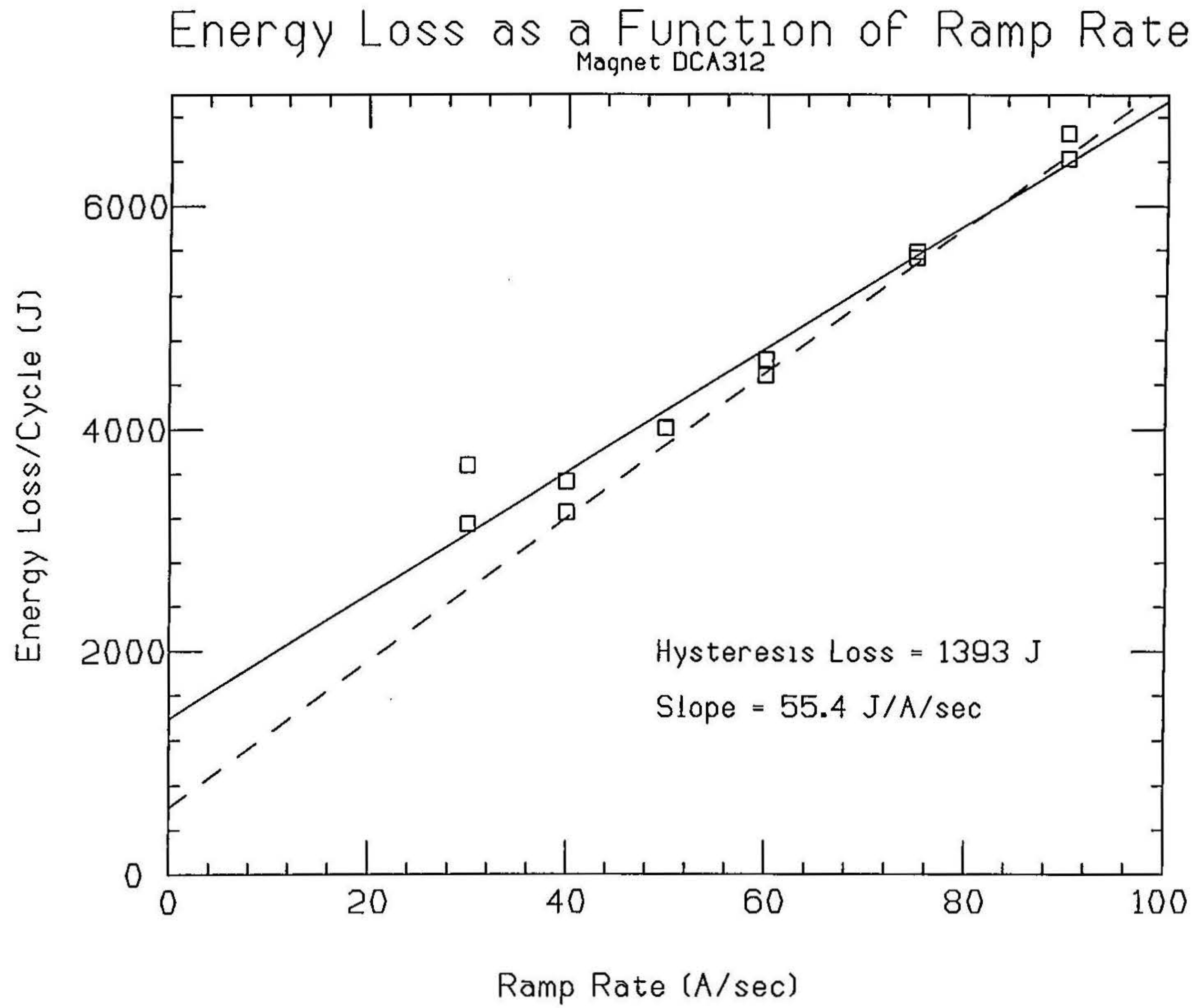
EDDY_LONG.TOP - Relationship between eddy current heating and quench dependence on ramp rate, all six magnets

6LONG_SU_50.TOP - Same as 6LONG_SU.TOP, except linear fits are for I-dot >= 50 A/sec data only

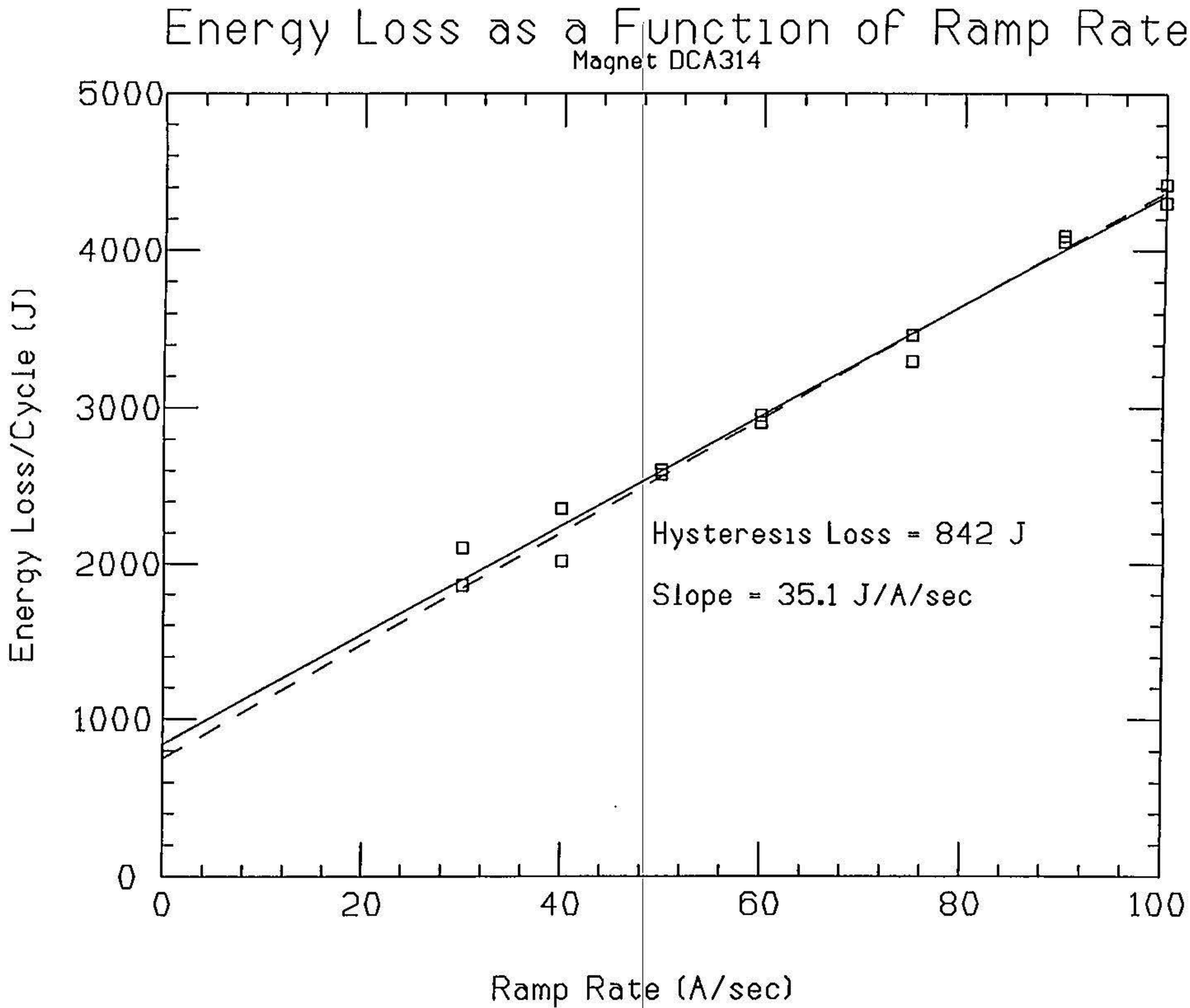
EDDY_LONG_50.TOP - Same as EDDY_LONG.TOP, except shows both data using only I-dot >= 50 A/sec values, and using all I-dot values in the eddy current heating calculation

DCA_RR.TOP - Quench current dependence on ramp rate, for all long magnets (courtesy D. Orris)

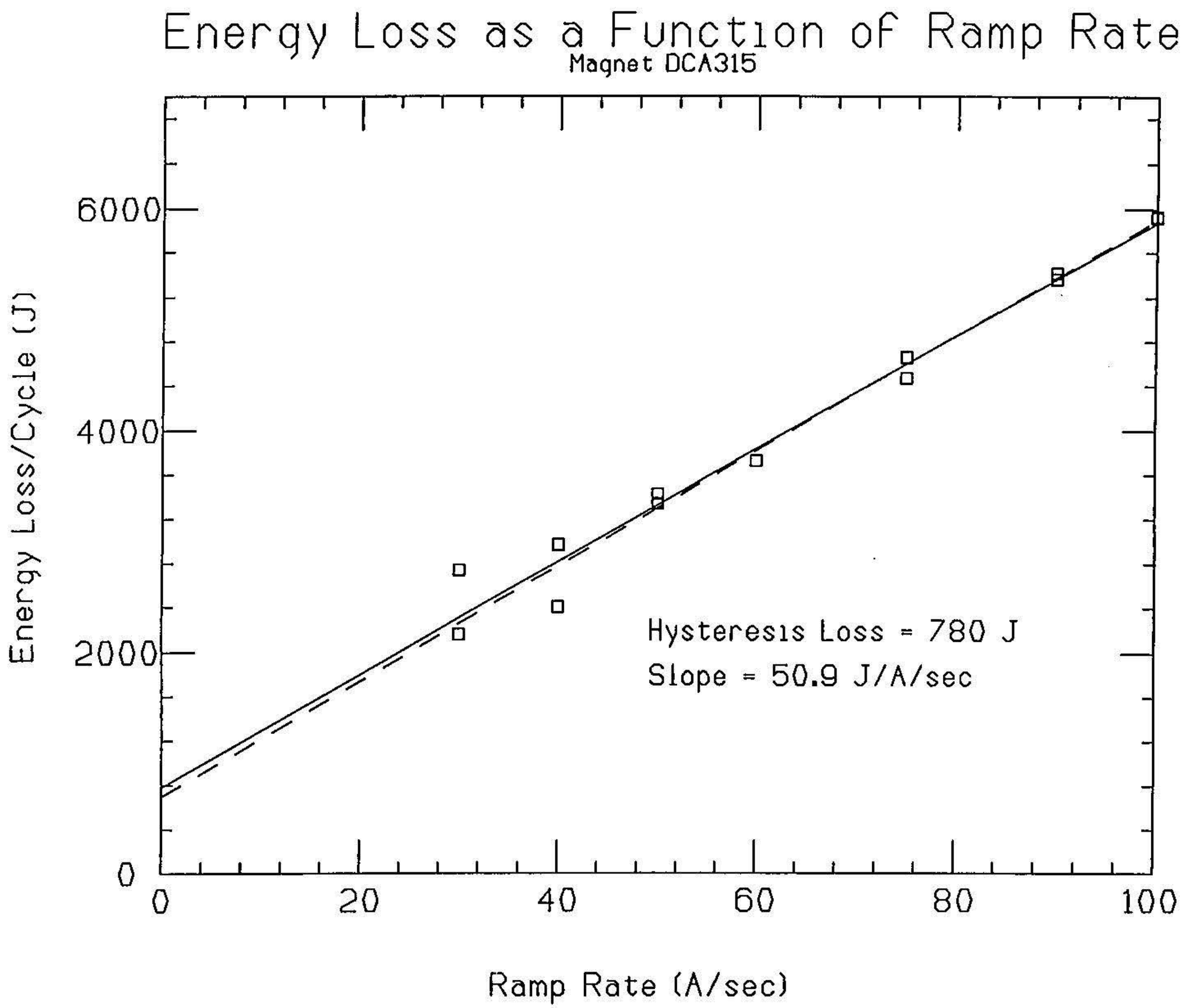

Energy Loss as a Function of Ramp Rate
Magnet DCA311
Energy Loss/Cycle (J)
0
1000
2000
3000
4000
0
50
100
150
200
Ramp Rate (A/sec)
Hysteresis Loss = 614 J
Slope = 15.7 J/A/sec



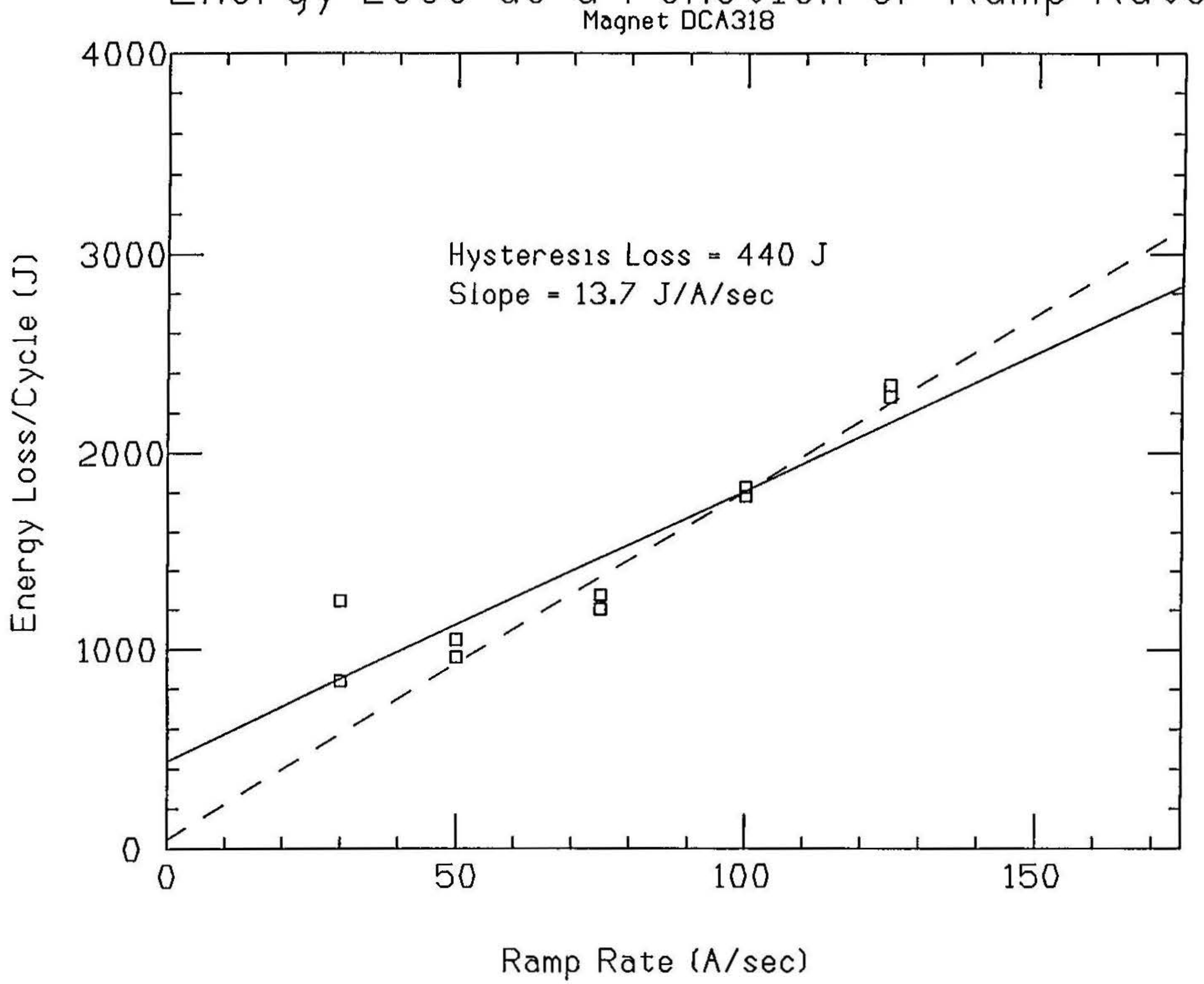
Energy Loss as a Function of Ramp Rate
Magnet DCA312
Energy Loss/Cycle (J)
6000
4000
2000
0
0
20
40
60
80
100
Ramp Rate (A/sec)
Hysteresis Loss = 1393 J
Slope = 55.4 J/A/sec

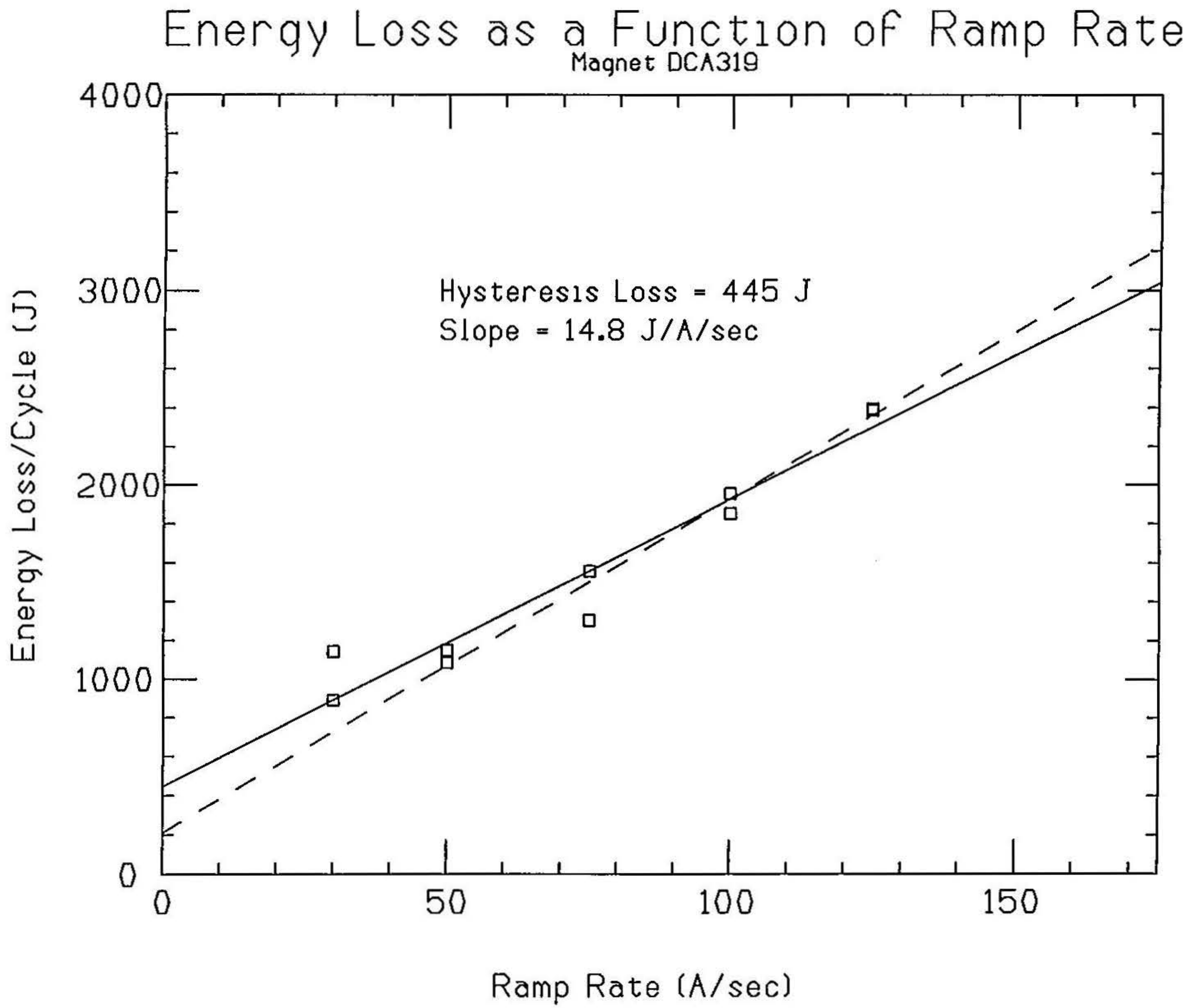


Energy Loss as a Function of Ramp Rate
Magnet DCA314
Energy Loss/Cycle (J)
Ramp Rate (A/sec)
Hysteresis Loss = 842 J
Slope = 35.1 J/A/sec
0
1000
2000
3000
4000
5000
0
20
40
60
80
100

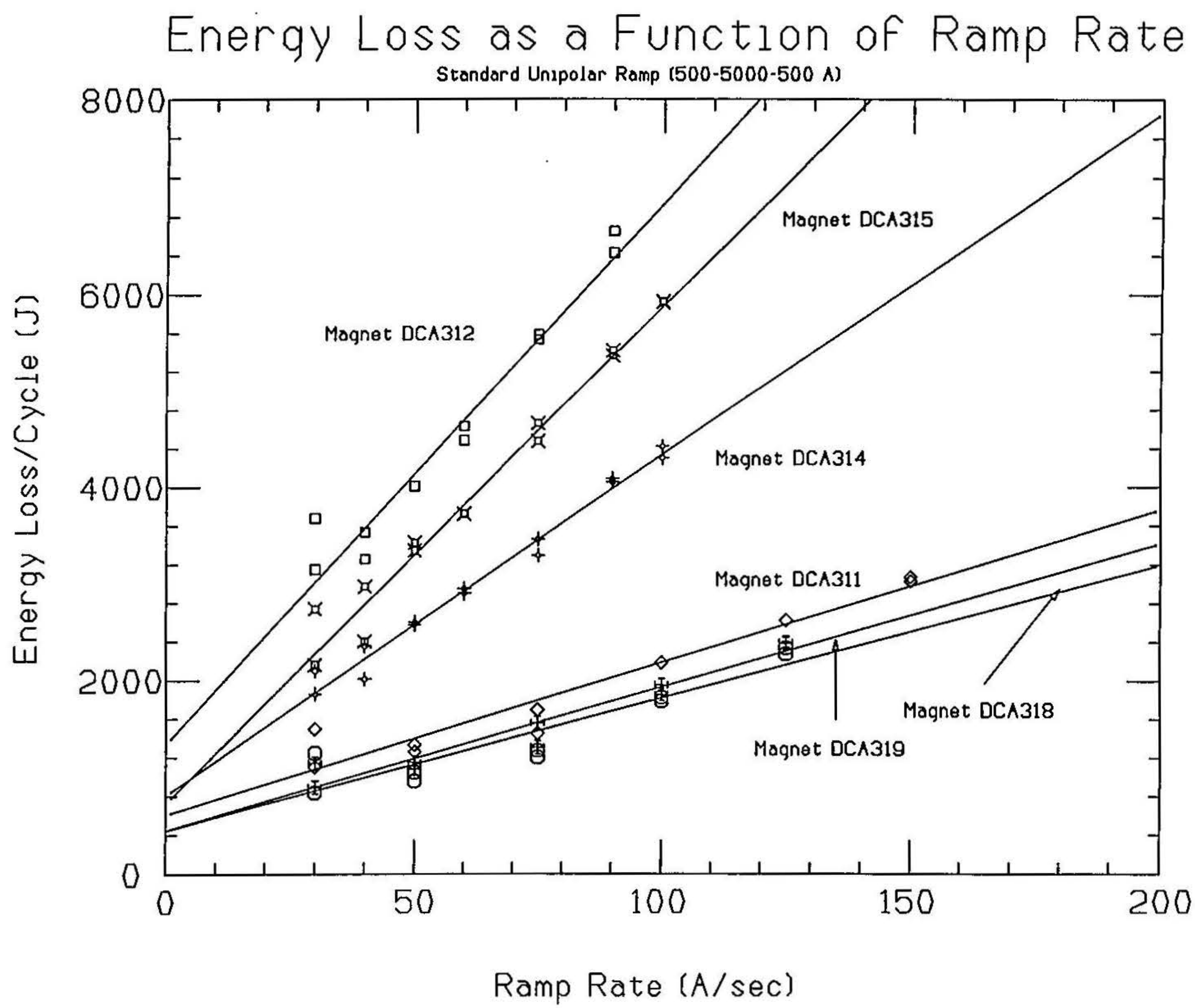

Energy Loss as a Function of Ramp Rate
Magnet DCA315
Energy Loss/Cycle (J)
6000
4000
2000
0
0
20
40
60
80
100
Ramp Rate (A/sec)
Hysteresis Loss = 780 J
Slope = 50.9 J/A/sec

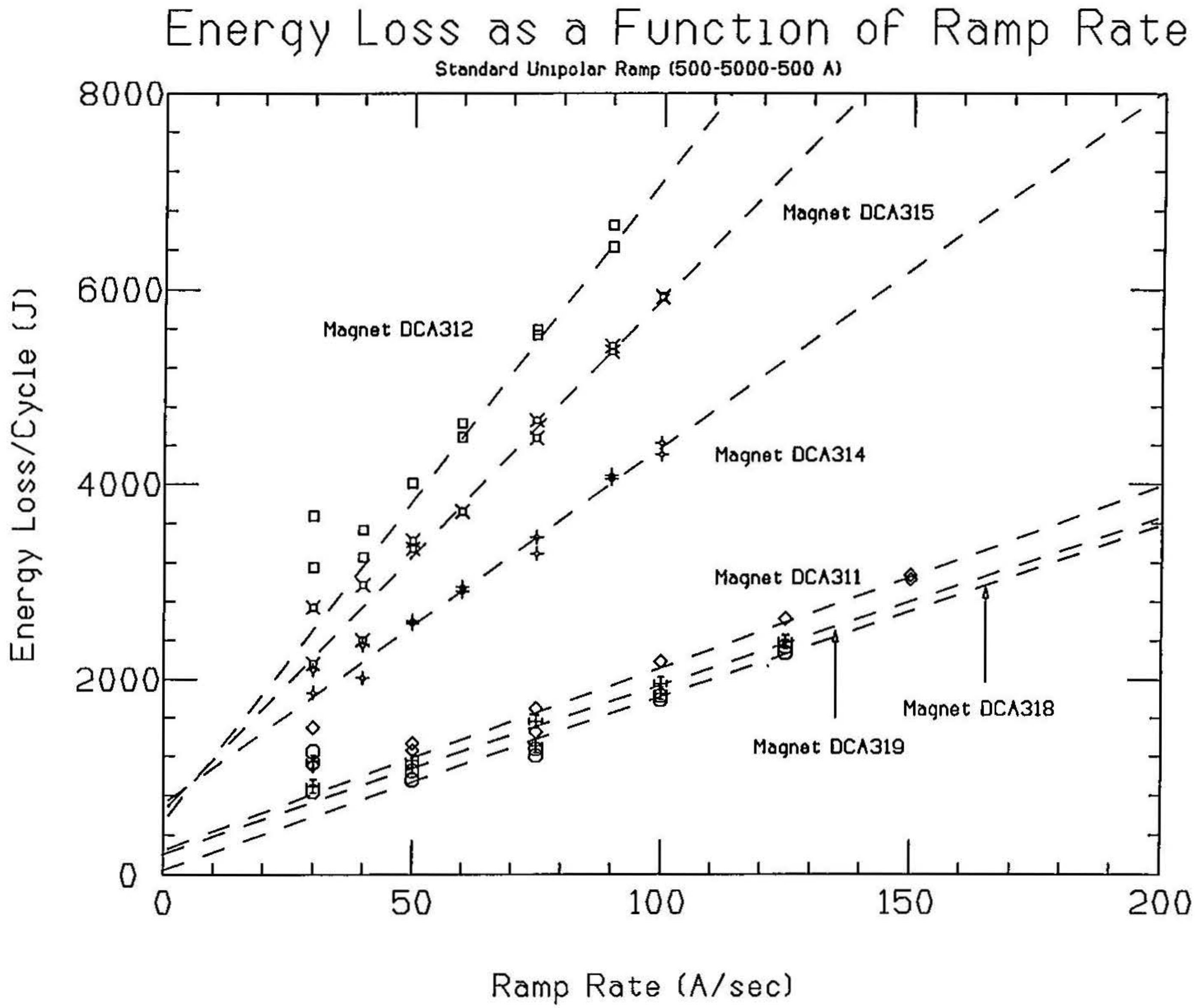
Energy Loss as a Function of Ramp Rate

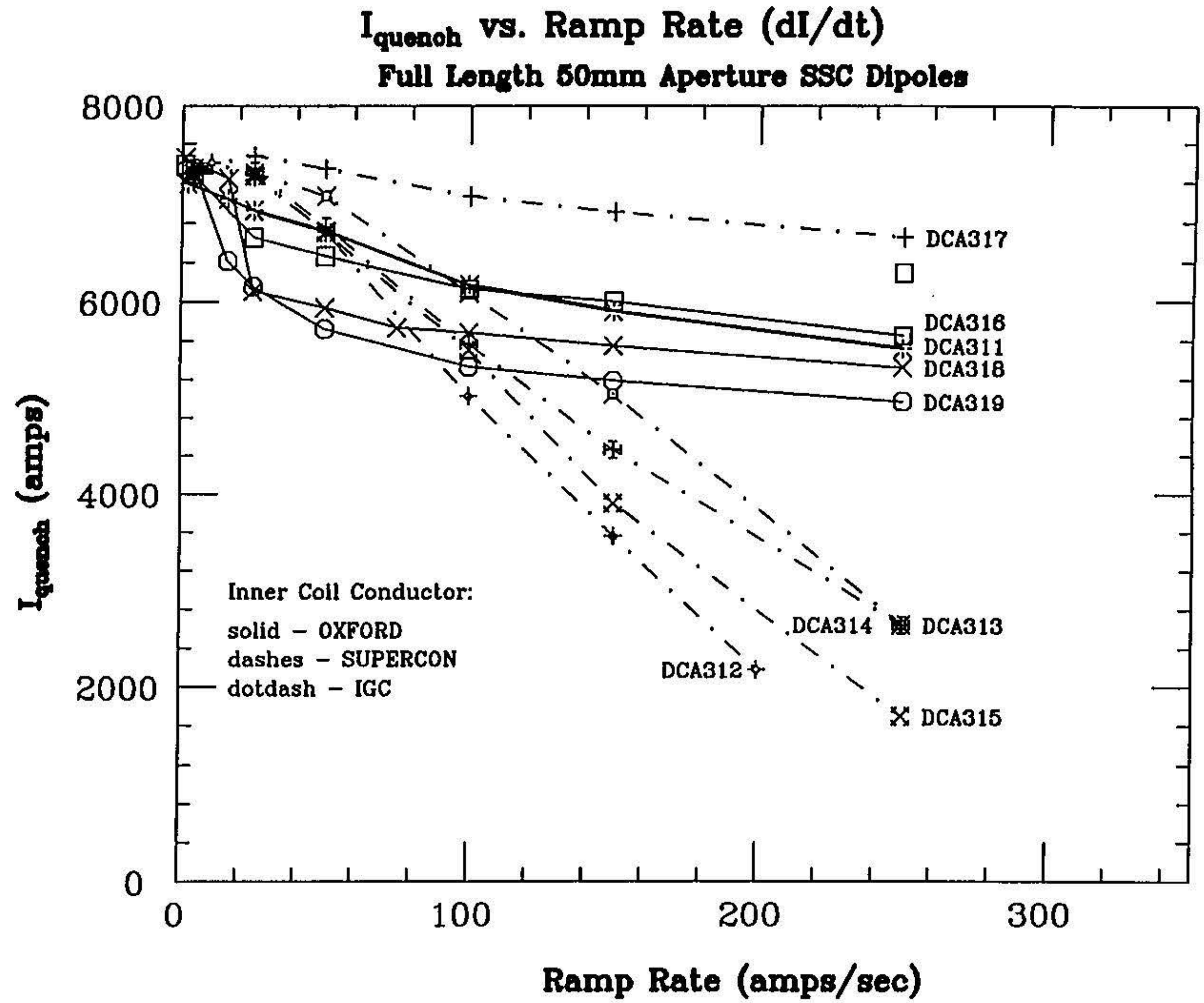




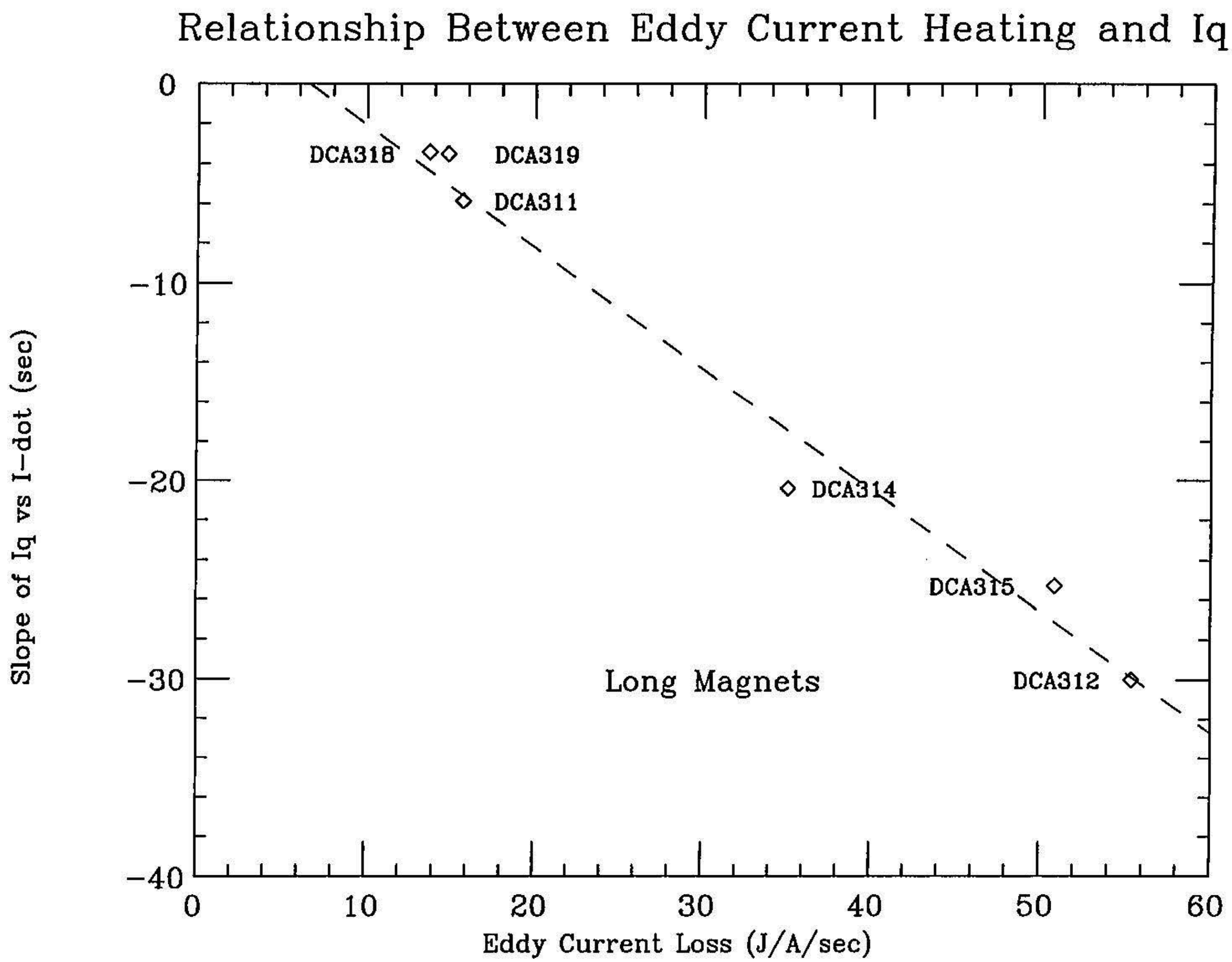
Energy Loss as a Function of Ramp Rate
Magnet DCA319
Hysteresis Loss = 445 J
Slope = 14.8 J/A/sec
Energy Loss/Cycle (J)
0
1000
2000
3000
4000
0
50
100
150
Ramp Rate (A/sec)

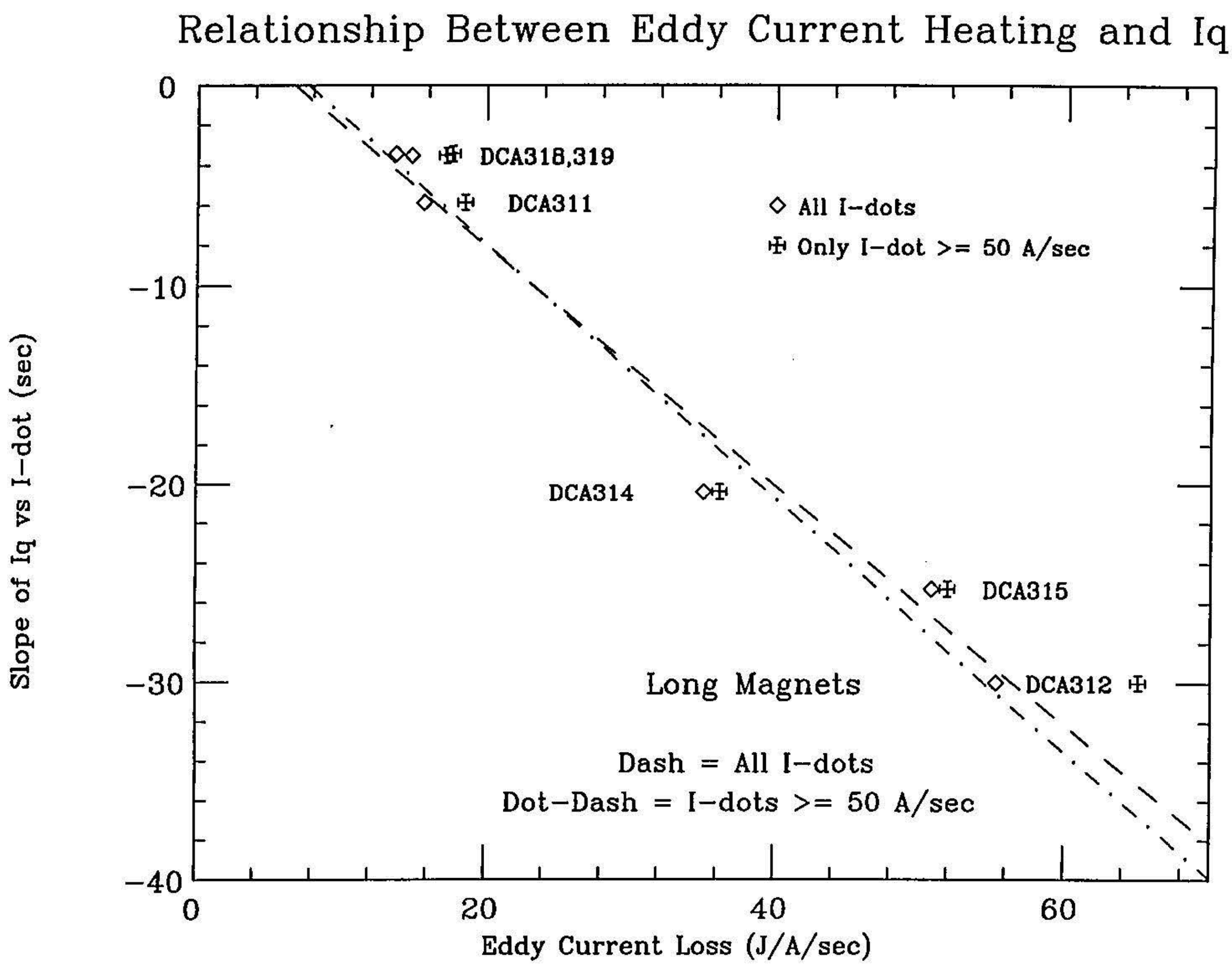

Energy Loss as a Function of Ramp Rate
Standard Unipolar Ramp (500-5000-500 A)
Energy Loss/Cycle (J)
8000
6000
4000
2000
0
0
50
100
150
200
Ramp Rate (A/sec)
Magnet DCA312
Magnet DCA315
Magnet DCA314
Magnet DCA311
Magnet DCA318
Magnet DCA319


Energy Loss as a Function of Ramp Rate
Standard Unipolar Ramp (500-5000-500 A)
8000
6000
4000
2000
0
0
50
100
150
200
Energy Loss/Cycle (J)
Ramp Rate (A/sec)
Magnet DCA315
Magnet DCA312
Magnet DCA314
Magnet DCA311
Magnet DCA318
Magnet DCA319



I quench vs. Ramp Rate (dI/dt)
Full Length 50mm Aperture SSC Dipoles
8000
6000
4000
2000
0
0
100
200
300
Ramp Rate (amps/sec)
I quench (amps)
DCA317
DCA316
DCA311
DCA318
DCA319
DCA314
DCA313
DCA312
DCA315
Inner Coil Conductor:
solid – OXFORD
dashes – SUPERCON
dotdash – IGC


Relationship Between Eddy Current Heating and Iq
Slope of Iq vs I-dot (sec)
Eddy Current Loss (J/A/sec)
DCA318
DCA319
DCA311
DCA314
DCA315
DCA312
Long Magnets
0
−10
−20
−30
−40
0
10
20
30
40
50
60


Relationship Between Eddy Current Heating and Iq
0
-10
-20
-30
-40
0
20
40
60
Slope of Iq vs I-dot (sec)
Eddy Current Loss (J/A/sec)
DCA318,319
DCA311
DCA314
DCA315
DCA312
All I-dots
Only I-dot >= 50 A/sec
Long Magnets
Dash = All I-dots
Dot-Dash = I-dots >= 50 A/sec