TS-SSC 91-158

TEST RESULTS OF FERMILAB 50 mm APERTURE MODEL DIPOLES

TARIQ JAFFERY
FERMI NATIONAL ACCELERATOR LABORATORY
6-AUGUST-1991

EXECUTIVE SUMMARY FOR TARIQ JAFFERY 8/6/91 (MSIM)

TITLE: TEST RESULTS OF FERMILAB 50 mm APERTURE MODEL DIPOLES

-DSA323 AND DSA324 (2ND & 3RD) FERMILAB 50 mm APERTURE MODEL DIPOLES TESTED AT FERMILAB . BOTH SHOWED VERY LITTLE TRAINING AND PLATEAUED ABOVE THE PREDICTED CURRENT

PLATEAU CURRENTS :

TEMP (K)	TC1	TC2	TC3	TC4	
4.2	7682 A	7638 A	7659 A		
4.35	7418 A	7442 A	7431 A	7413 A	DSA323
3.8		8119 A			
4.2	7678 A	7735 A	7624 A		DSA324
4.35	7437 A	7483 A	7390 A		
3.8		8190 A			

- AUTOPSY ON DSA323 IS IN PROGRESS TO INVESTIGATE DOWN RAMP QUENCHES IN RETURN END OF LOWER INNER POLE TURN . PRELIMINARY RESULTS SHOW :

a) THE SADDLE SURFACES ARE NOT FLUSH WITH THE END CAP , SINCE THEY ARE NOT PLANAR AND DO NOT EXTEND BEYOND THE PLANE OF THE END INSULATORS .

b) MANUFACTURING DEFECTS IN END PLATE PERHAPS CAUSED:
(i) ALL BULLET BUSHING SCREWS TO BE TORQUED PAST THE 30 IN-LBS LIMIT INORDER TO ACHIEVE 200 LBS FORCE PER BULLET (AS SPECIFIED BY THE PROCEDURE)
(ii) ONLY ONE OF THE LEAD END SET SCREWS WAS MAKING CONTACT WITH THE END CAP

DSA324 IS COLD AND STILL BEING TESTED

ACLOSS MEASUREMENTS ON DSA324 WERE DONE. FOR UNIPOLAR RAMP CYCLE OF 500-5000 A THERE IS A NET HYSTERESIS LOSS OF 109 JOULES/CYCLE AND FOR BIPOLAR RAMP CYCLE OF 0-5000-0-(-5000) A THE SAME LOSS IS UP BY A FACTOR OF 3 (300 JOULES /CYCLE) .

THE QUENCH PROPAGATION VELOCITY DURING A PLATEAU QUENCH (AT 16 A/S) IS ~80 m/s IN THE STRAIGHT SECTION OF THE HIGHEST FIELD REGION (POLE TURNS) . WHEREAS IN THE RAMP SPLICE THE QUENCH VELOCITY CAN BECOME AS SMALL AS ~33 m/s . ALL THE STANDARD PLATEAU QUENCHES WERE IN THE POLE TURN AND THE MAGNET PLATEAUED WELL ABOVE THE SSC OPERATING MARGIN .

TEST RESULTS OF FERMILAB 50 mm APERTURE MODEL DIPOLES

I. INTRODUCTION

II. QUENCH BEHAVIOR

III. MECHANICAL BEHAVIOR

IV. HARMONICS

V. ACLOSS (EIEIO) STUDIES

VI. PERIODIC REMNANT FIELDS

TEST FACILITY
SUPERCONDUCTING MAGNET R&D LABORATORY (LAB2)

3 Vertical Dewars (Longest 3.6 Meters)
- Temperature Range 3.2 K to 4.35 K
- Instrumented with Pressure Transducers, Liquid Level Gauges, and Thermometers

Power Supplies 3 Transrex 500-5
- With 1 Supply at constant current
  - <.1amp RMS Point to Point Scatter
  - <.2 amp long term drift
  - No detectable over/under shoot
- With 1 Supply at zero current
  - No detectable scatter, drift, or over/under shoot

Data Acquisiton
- Micro-Vax
- CAMAC Based

Magnetic Measurement System
- Multiple Winding Morgan Coil 1 inch Radius
- Rotation of Probe at 6 Hz
- In Anti-Cryostat Inserted in Magnet Bore
- V/F Converter Based Measuring System
- Maximum Data Acquisition Rate 3 Hz

TITLE: TEST RESULTS OF FERMILAB 50 mm APERTURE MODEL DIPOLES

(DSA323 AND DSA324 (2ND & 3RD) SHORT DIPOLES)

-DSA323 AND DSA324 SHOWED VERY LITTLE TRAINING AND PLATEAUED SLIGHTLY ABOVE THE PREDICTED CURRENT

DSA323	DSA324
S.S. END CLAMPS WITH AZIMUTHAL G10CR (LIKE DSA321) .	ALUMINUM END CLAMPS WITH AZIMUTHAL G10CR
HEATERS 2 SSC2- 24 IN	HEATERS 2 SSC2 -12 IN S. STEEL PADS
HEATERS 2 SSC2- 18 IN	HEATERS 2 SSC2 -12 IN S. STEEL PADS

- DIFFERENT COIL PRESTRESS
- BOTH HAVE VERTICALLY SPLIT YOKE ELEMENTS
- BOTH MAGNETS HAVE HIGH MANGANESE STEEL "FILLER" LAMINATIONS IN END REGIONS TO PREVENT THERMAL STRESSES IN SHELL

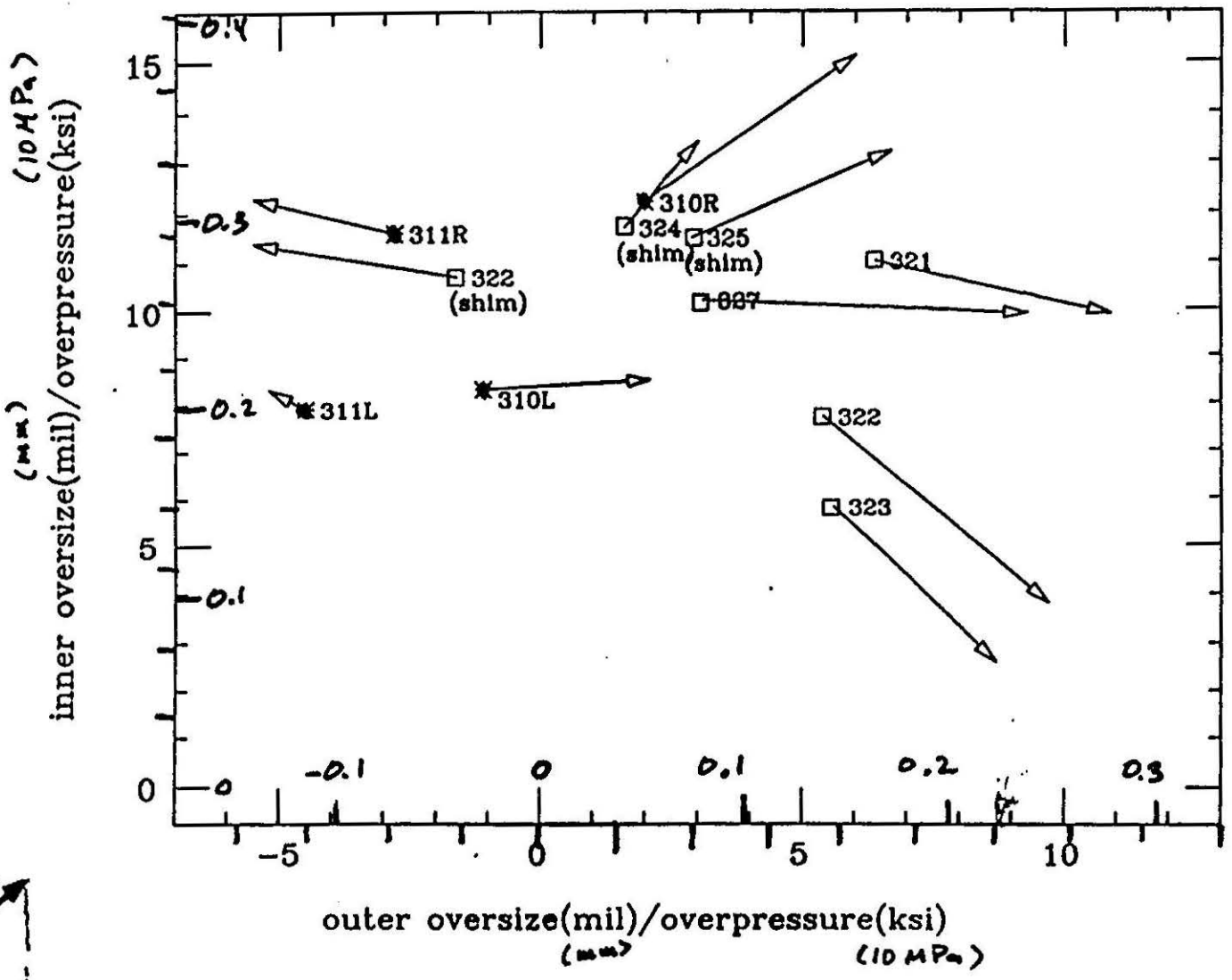
Table I

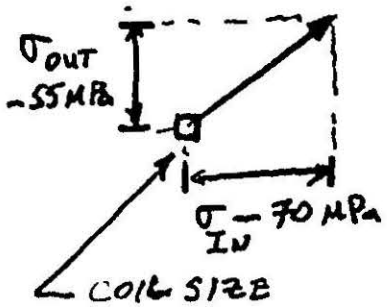
POLE SHIMS AND COIL PRESTRESS. THE UPPER (LOWER) ENTRY IN EACH PAIR CORRESPONDS TO THE INNER (OUTER) COIL.

Magnet		DSA321	322	323	324	325	327
Pole	0	0	0.13 in	0	0.13	0.13	0
Shim (mm)	0	0	-0.13 out	0	-0.13	0	0
Prestress (MPa)							
After collar	55-85	62	71	47	81	81	67
keying	40-70	91	27	76	65	81	98
Before shell		59		44	67		
welding		88	-	73	59	-	-
After shell		63		53	81		
welding		88	-	75	61	-	-
Before		62		52 (2.4 kG)	76		
cooldown		86	-	72 (10)	60	-	-
After		43		22 3.1	43		
cooldown		72	-	62 8.8	52	-	-
B=6.7 T	>14	18		4	22		
	>14	61	-	52	40	-	-

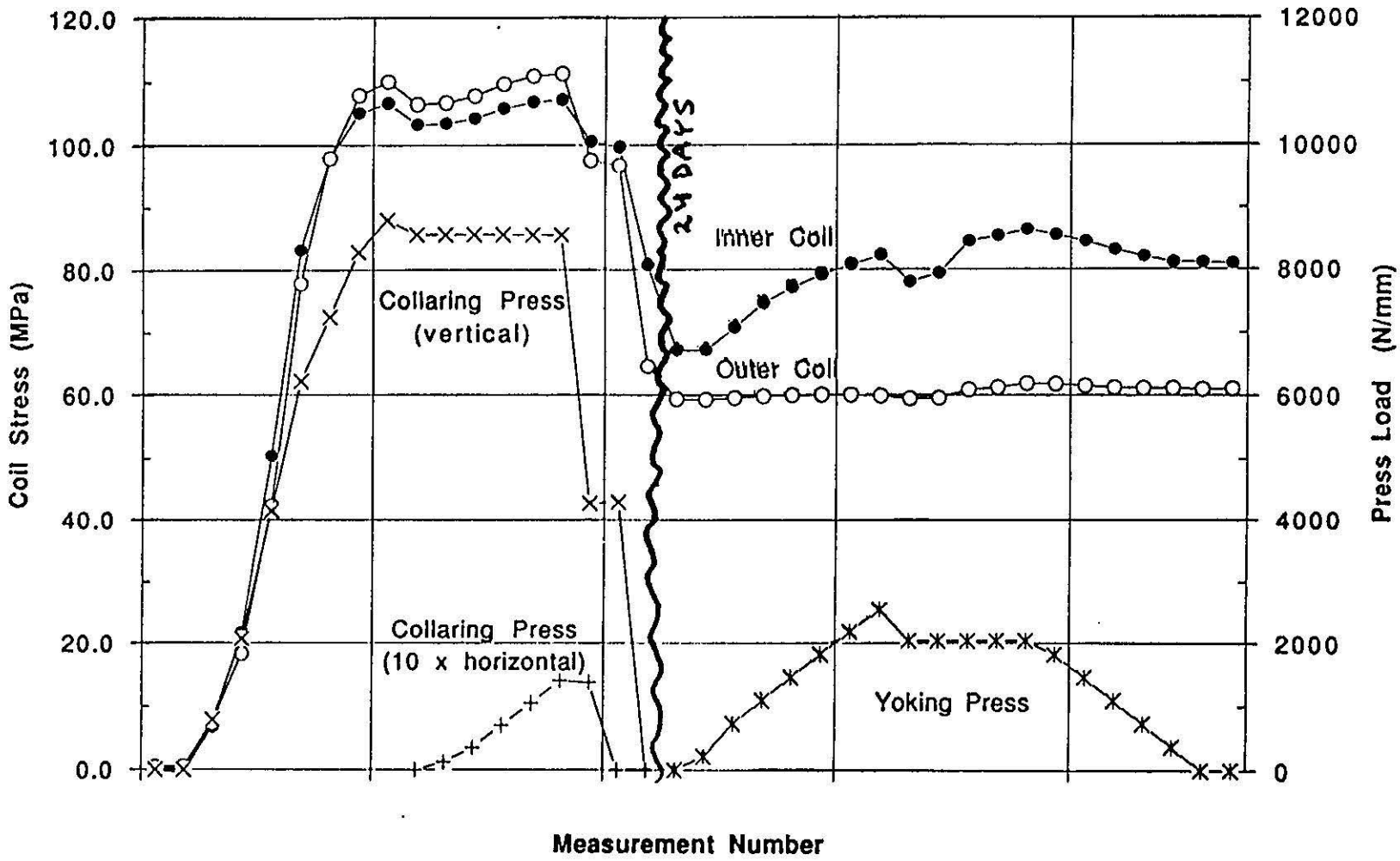
↑ DESIGN VALUES

DETERMINE CORRECT COIL AZIMUTHAL SIZE
FROM SHORT MAGNET SIZE VS. PRELOAD CORRELATION

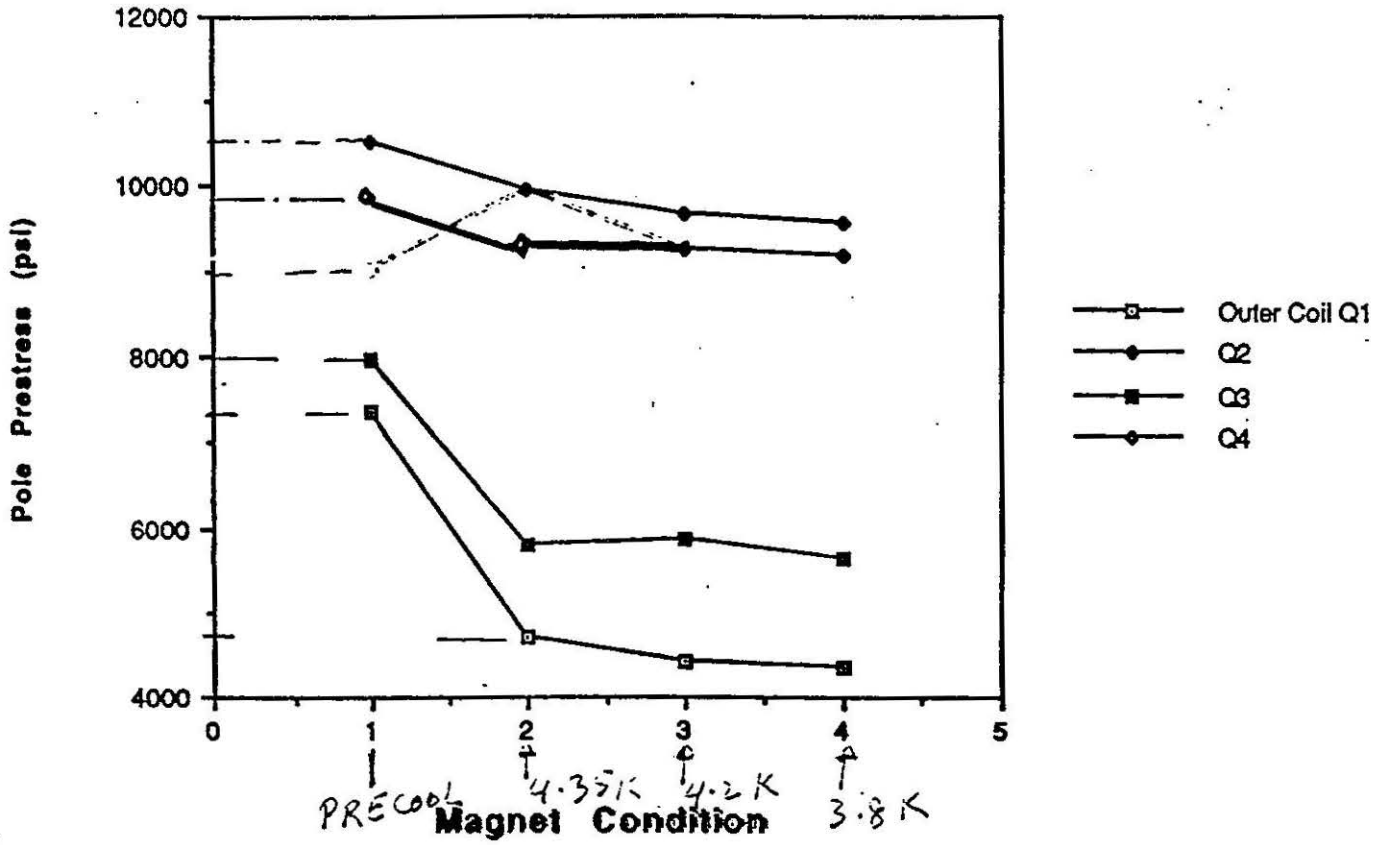




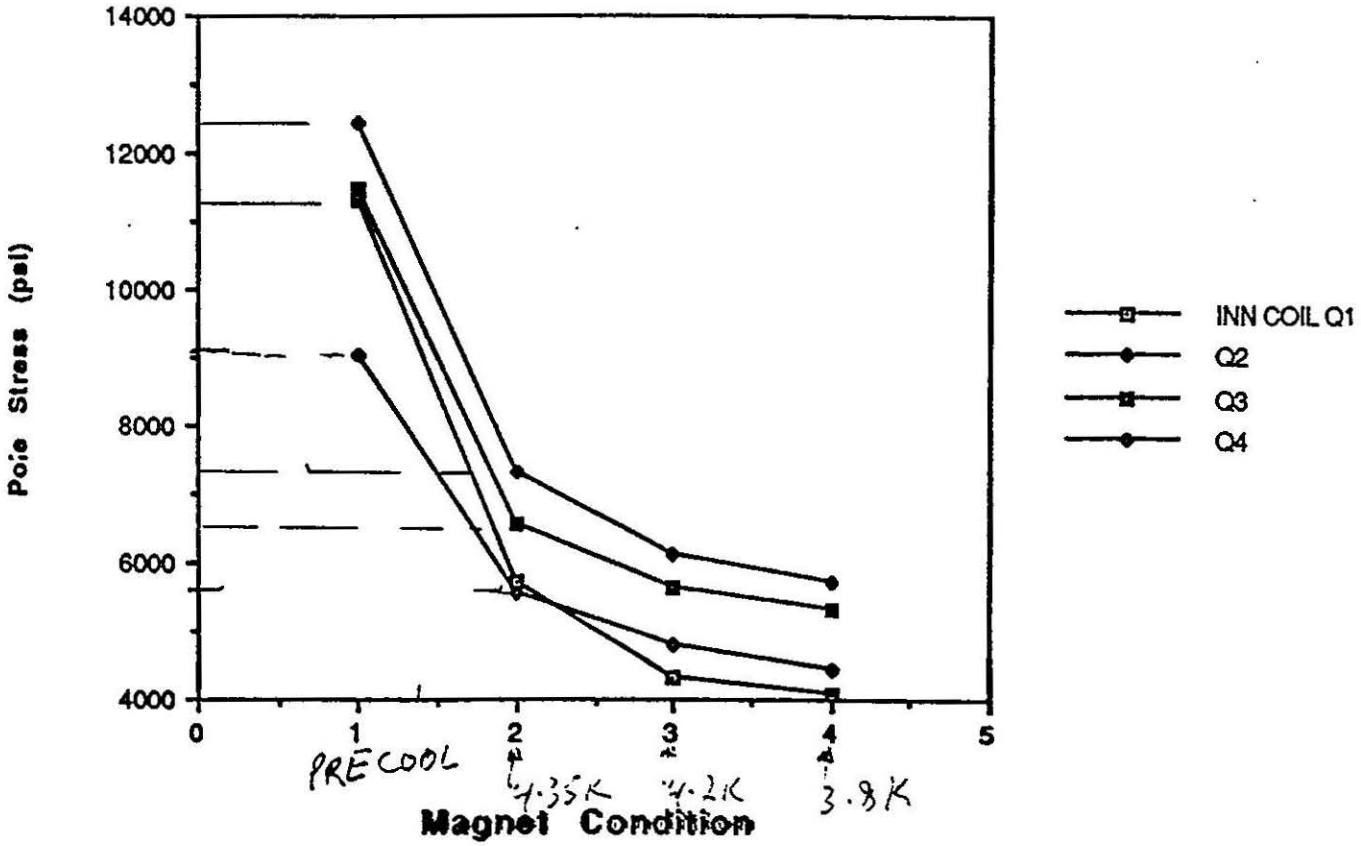
SSC


DSA324 Collaring (4/15/91) and Yoking (5/9/91)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Coil Stress (MPa)
12000
10000
8000
6000
4000
2000
0
Press Load (N/mm)
24 DAYS
Inner Coil
Outer Coil
Collaring Press
(vertical)
Collaring Press
(10 x horizontal)
Yoking Press
Measurement Number

DSA324 Outer Coil Pole Stress

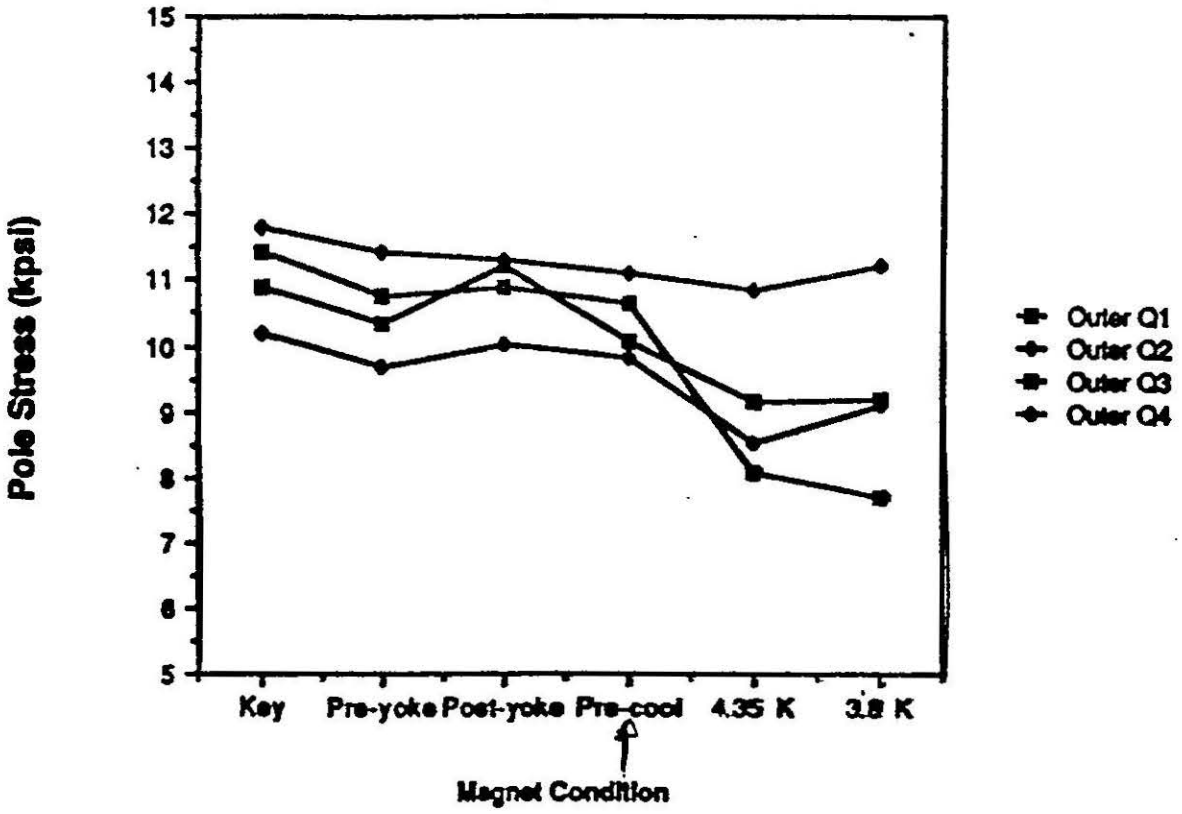


DSA324 Inner Coil Pole Stress



-1.7 KPSI Avg Pole stress Loss

DSA323 Outer Coil Pole Stress



Prestress Change with Cooldown
1.5 m Long, 50 mm Aperture
SSC Model Dipoles at Fermilab

Magnet	Coil Stress Change (MPa) Inner Coil	Outer Coil	End Force Change (kN)
DSA321	-19	-14	-1
DSA323	-30	-10	0
DSA324	-33	-8	1

JBS

DSA323 AND DSA324 HAVE SAME INNER CABLE

TEMP (K)	Icritical (kA)
4.22	7.47
4.35	7.31
3.8	7.96

SSC 3-S-00021
Ic =10,079 A AT 7 T, 4.22 K

*QUENCH CURRENT PREDICTED BY GREEN PARAMETRIZATION OF J,B,T SURFACE

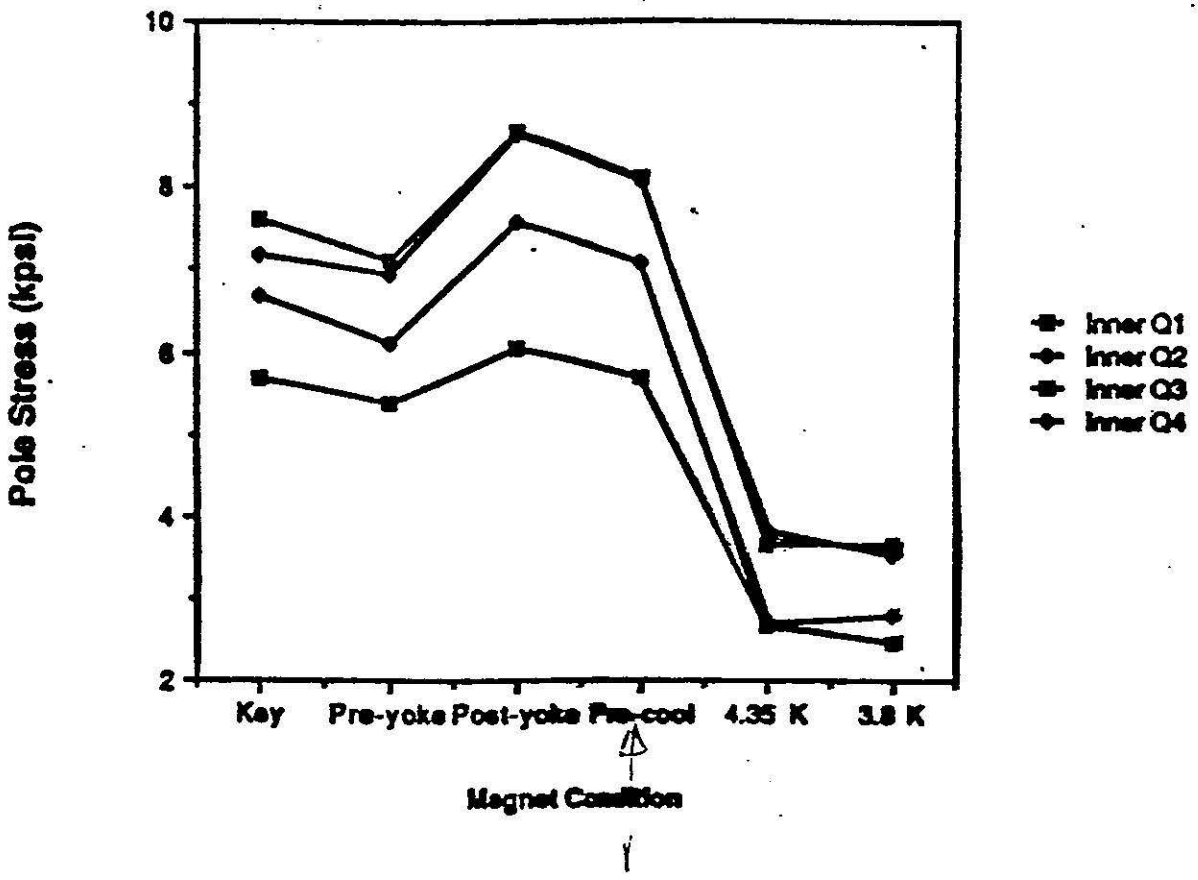
PLATEAU CURRENTS :

DSA323 # QUENCHES: 21 | 20 | 7 | 6

TEMP (K)	TC1	TC2	TC3	TC4	
4.2	>200A 7682 A	>160A 7638 A			
4.35	>100A 7418 A	>130A 7442 A	>120 7431 A	>100 7413 A	DSA323
3.8		>150 8119 A			
4.2	>200A 7678 A	>250A 7735 A	>150 7624 A		DSA324
4.35	>120 7437 A	>170 7483 A	>80 7390 A		
3.8		>230 8190 A	~8091 A		

DSA324 # QUENCHES: 22 | 44 | 17 (Tot 83 Q's)

DSA323 Inner Coil Pole Stress

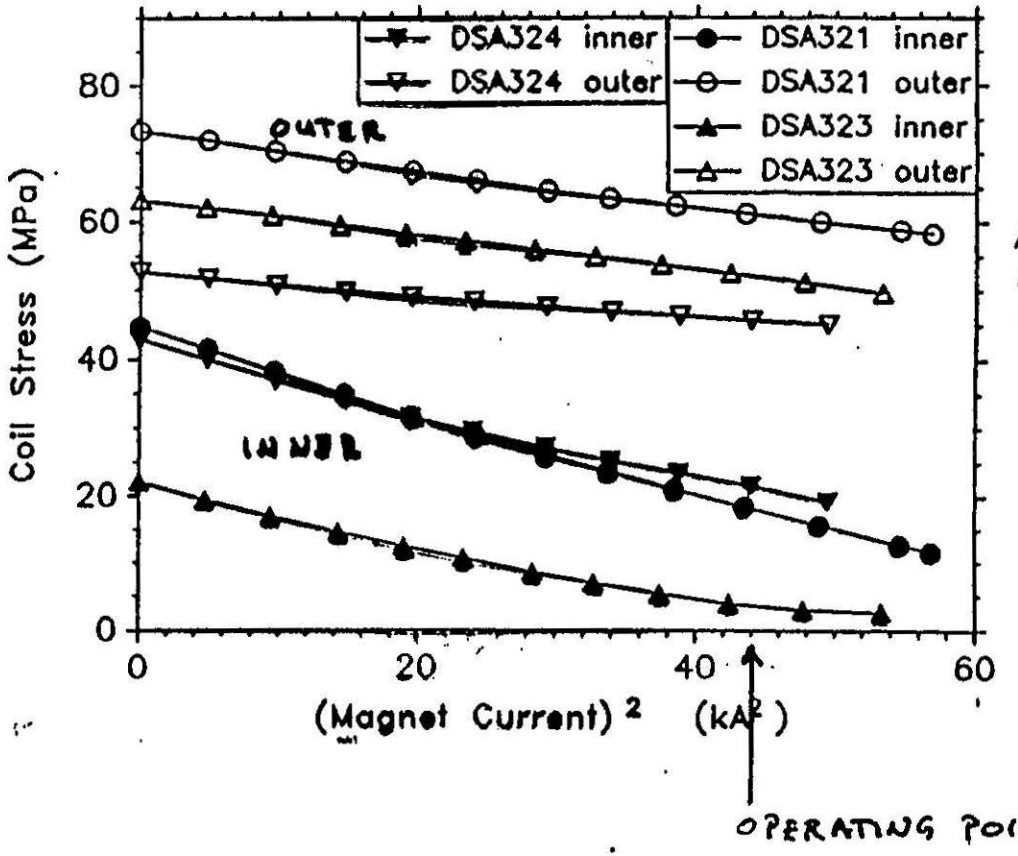


- 4.2 KPSI AVERAGE POLE STRESS LOSS

- APPARENT ASYMMETRY BETWEEN LEFT AND RIGHT QUADRANT PAIRS

Coil Stress vs. Magnet Excitation

Fermilab–built 1.5 m long, 50 mm aperture SSC collider dipoles

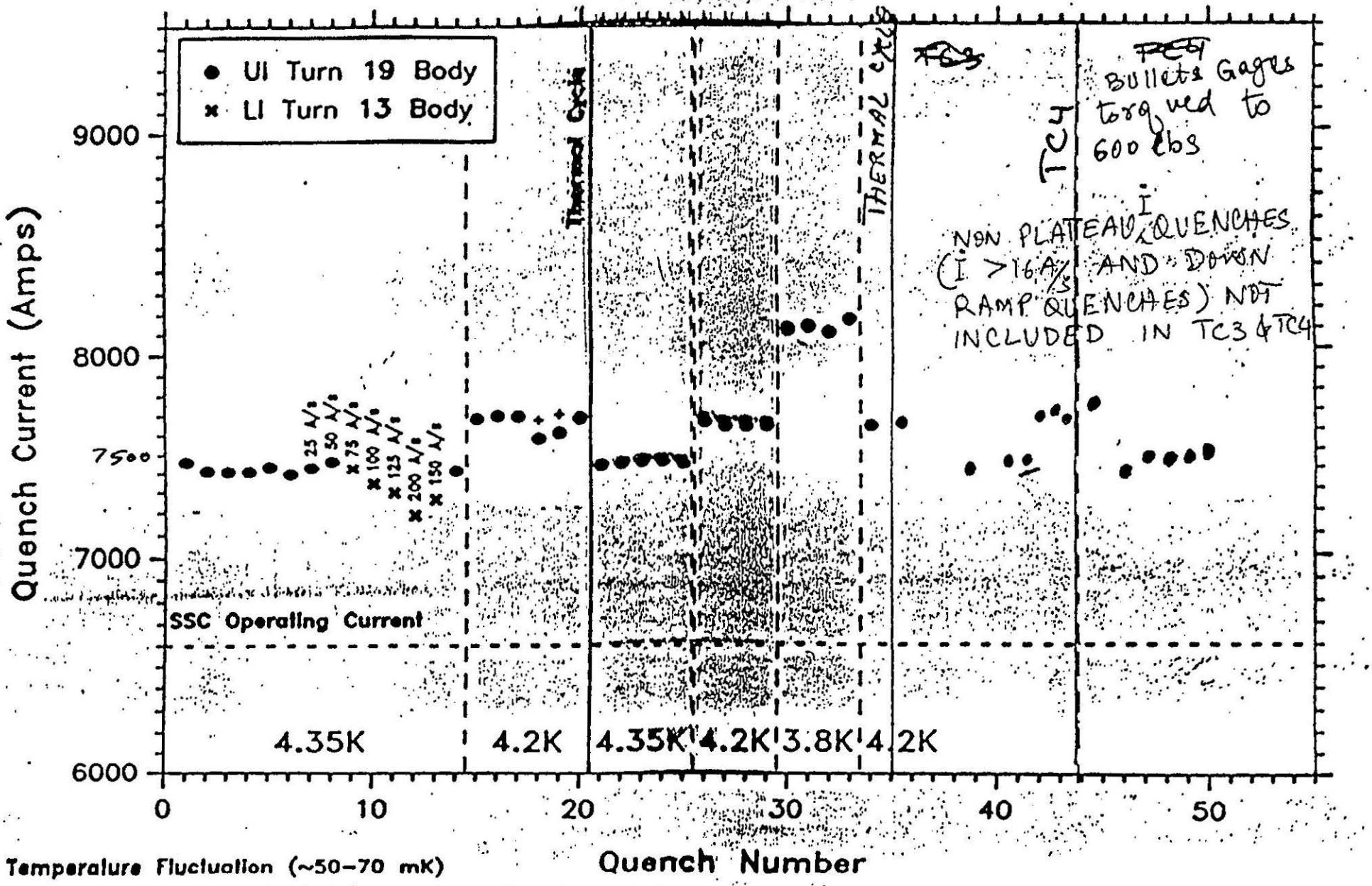


ALL OUTER PRESTRESS ARE HIGHER THAN NECESSARY

DSA323 INNER PRESTRESS IS TOO LOW

DSA323 Quench History

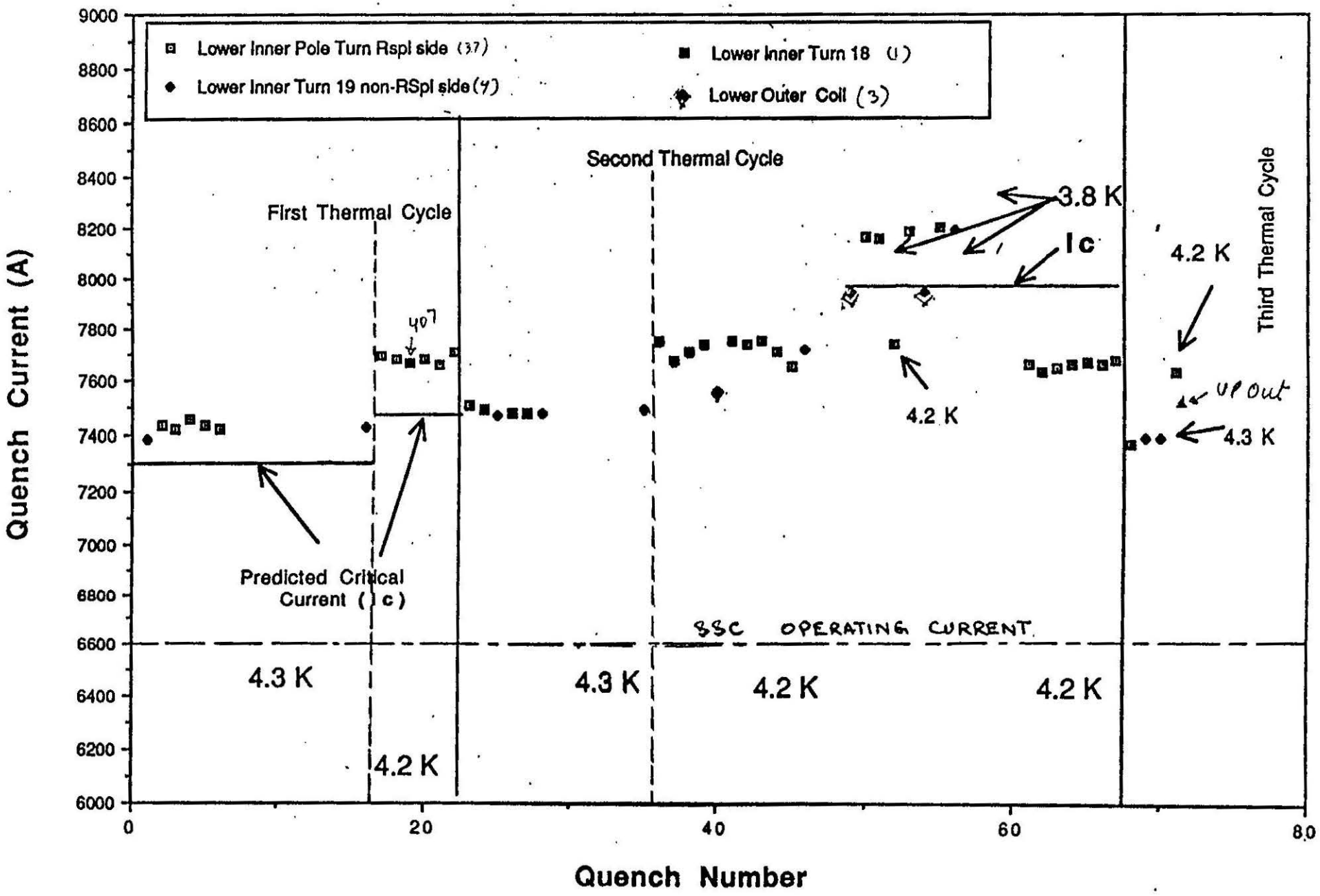
(Second Fermilab built 50 mm aperture, 1.5 m long SSC dipole)

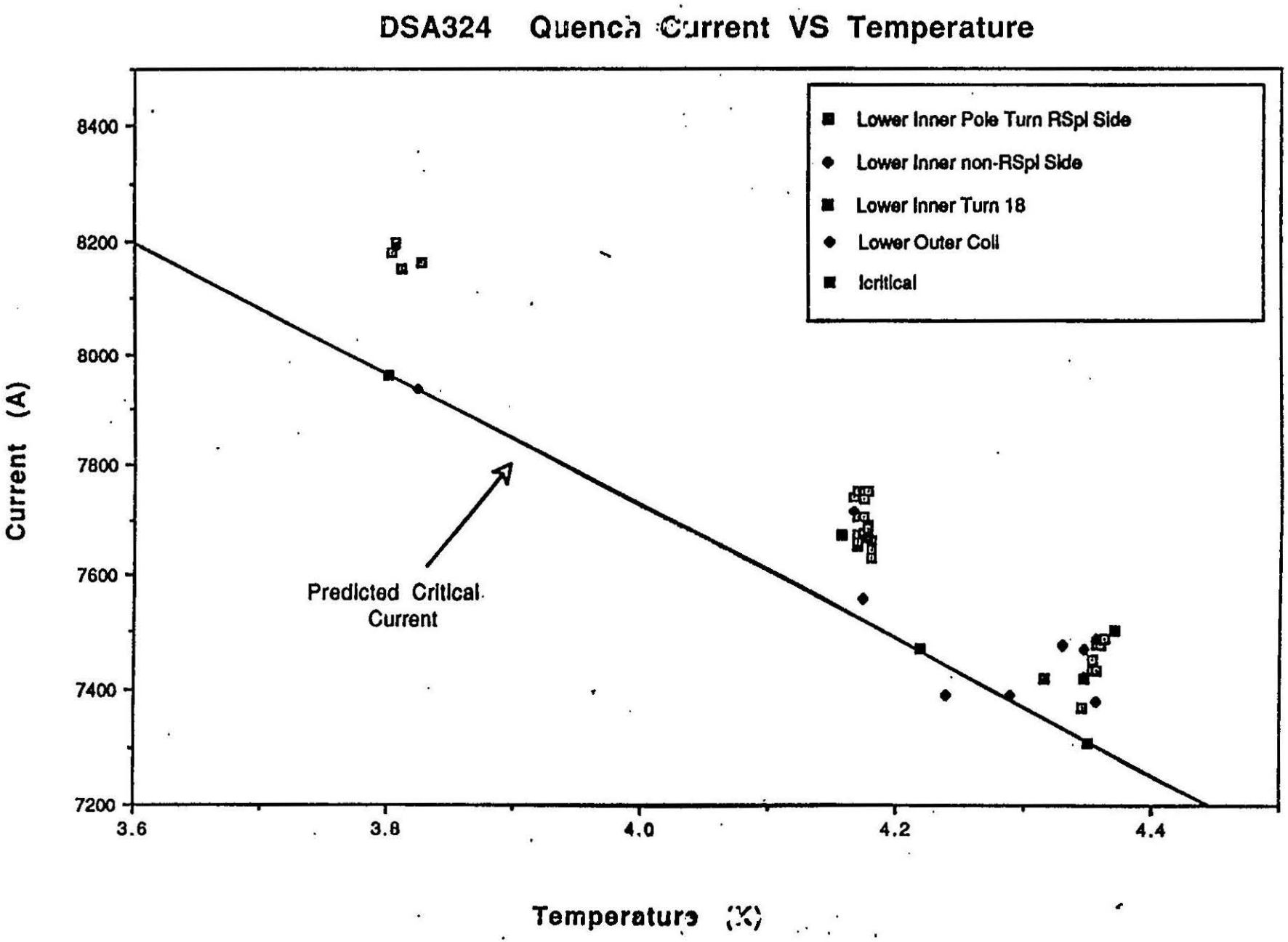


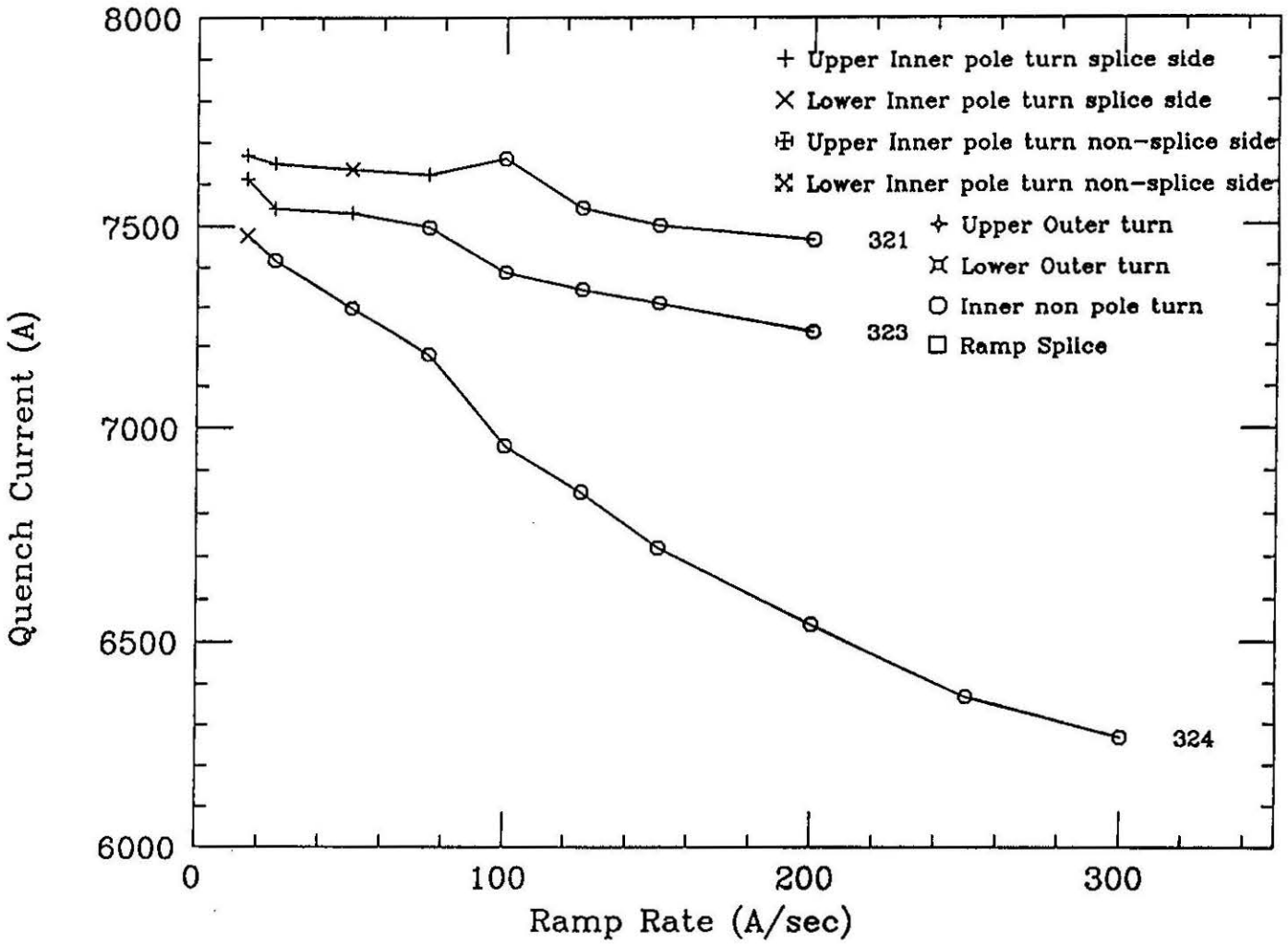
+ Temperature Fluctuation (~50–70 mK)

Note: All quenches are at 16 A/sec unless otherwise noted.

DSA324 QUENCH HISTORY




DSA324 Quench Current VS Temperature
Lower Inner Pole Turn RSpl Side
Lower Inner non-RSpl Side
Lower Inner Turn 18
Lower Outer Coil
Icritical
Predicted Critical Current
Current (A)
8400
8200
8000
7800
7600
7400
7200
3.6
3.8
4.0
4.2
4.4
Temperature (K)


8000
7500
7000
6500
6000
0
100
200
300
Quench Current (A)
Ramp Rate (A/sec)
+ 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
324

- AUTOPSY ON DSA323 IS IN PROGRESS TO INVESTIGATE DOWN RAMP QUENCHES IN RETURN END OF INNER POLE TURN .

PRELIMINARY RESULTS SHOW :

a) (i)INNER OUTER COIL RETURN END SADDLE SURFACES ARE PLANAR IN DSA321 , AND ii) THEY ARE ~25 MILS FURTHER OUT TOWARD THE END OF THE MAGNET THAN THAT OF THE INSULATORS

c) IN DSA323, THE INNER AND OUTER RETURN END SADDLE SURFACES ARE NOT FLUSH WITH THE END CAP , THEY ARE NOT PLANAR AND DO NOT EXTEND BEYOND THE PLANE OF THE END INSULATORS .

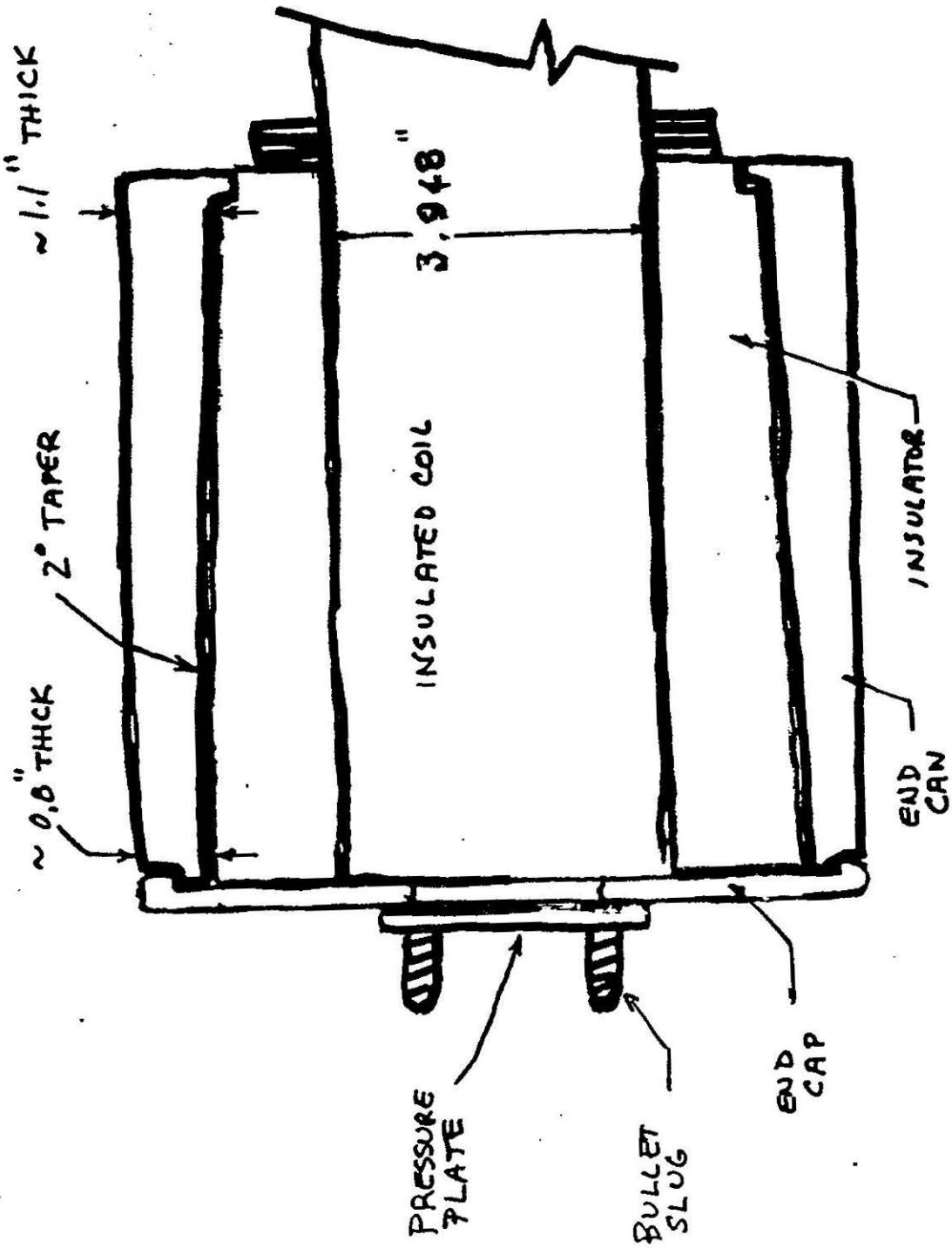
d) MANUFACTURING DEFECTS IN END PLATE PERHAPS CAUSED:

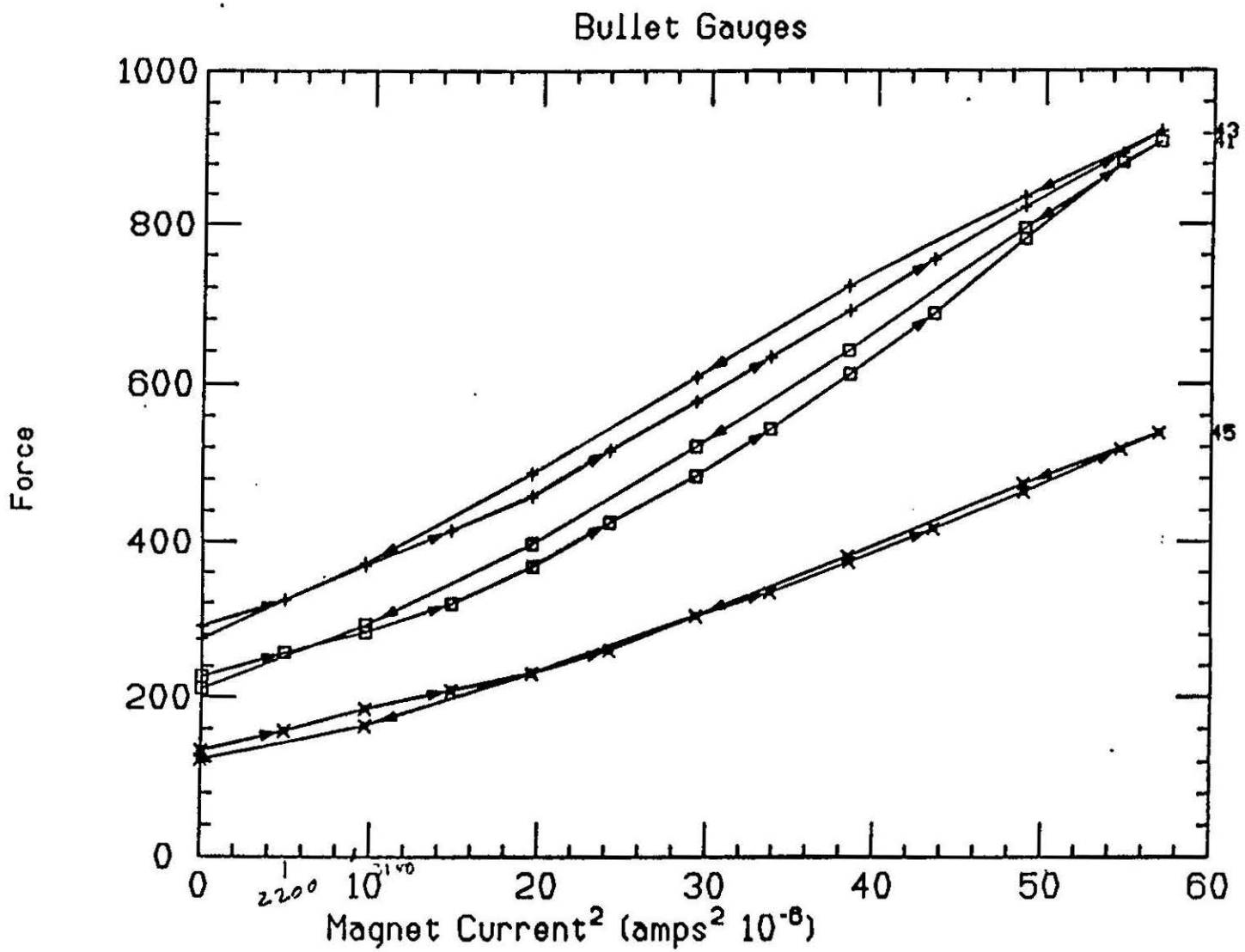
(i) ALL BULLET BUSHING SCREWS TO BE TORQUED PAST THE 30 IN-LBS LIMIT INORDER TO ACHIEVE 200 LBS FORCE PER BULLET (AS SPECIFIED BY THE PROCEDURE)

(ii) ONLY ONE OF THE LEAD END SET SCREWS WAS MAKING CONTACT WITH THE END CAP

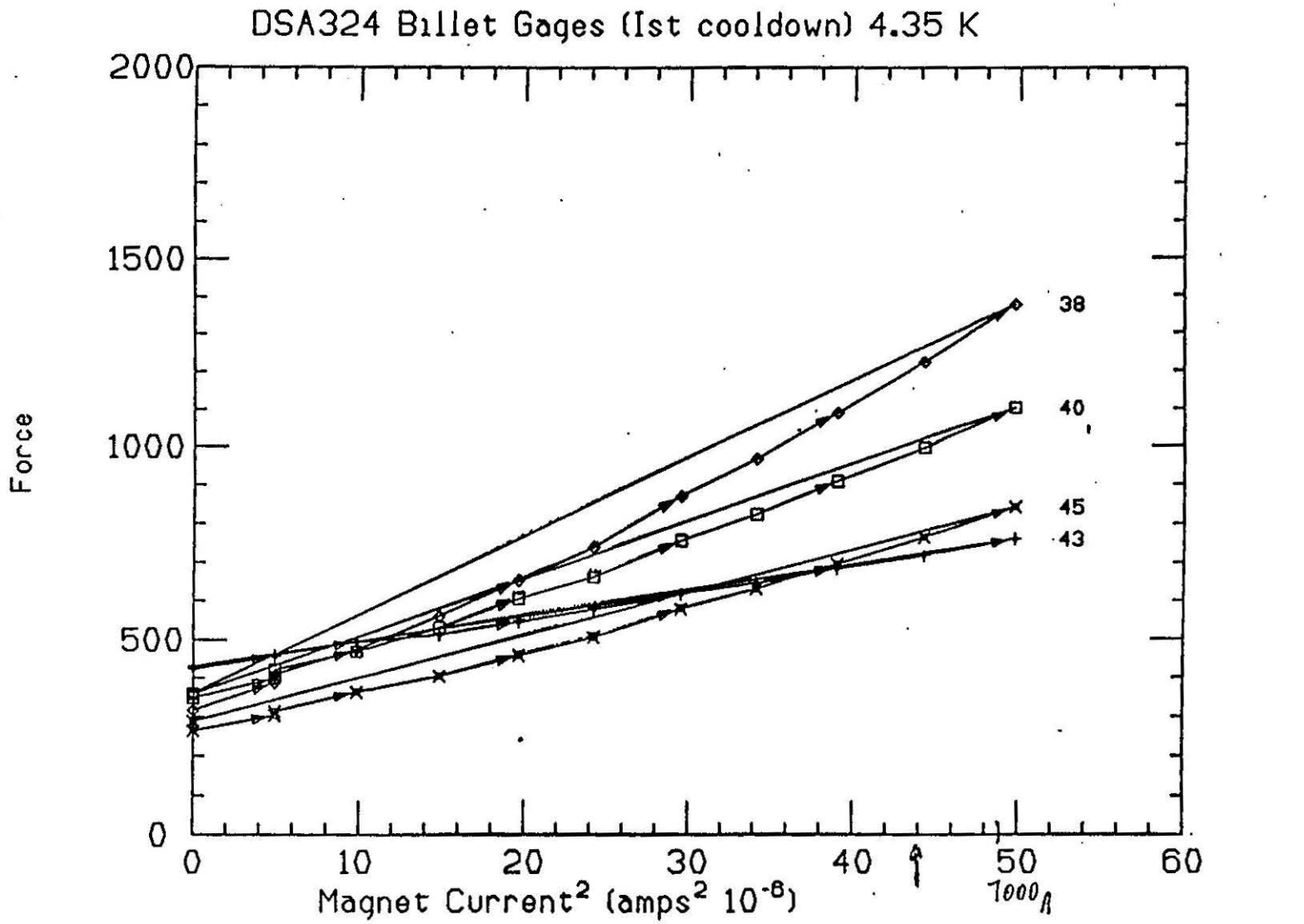
SADDLE SURFACES ON (INNER AND OUTER COIL) RET. END ARE NOT PLANAR

MANUFACTURING DEFECTS IN END (LEAD END AND NON-LEAD END) PLATES

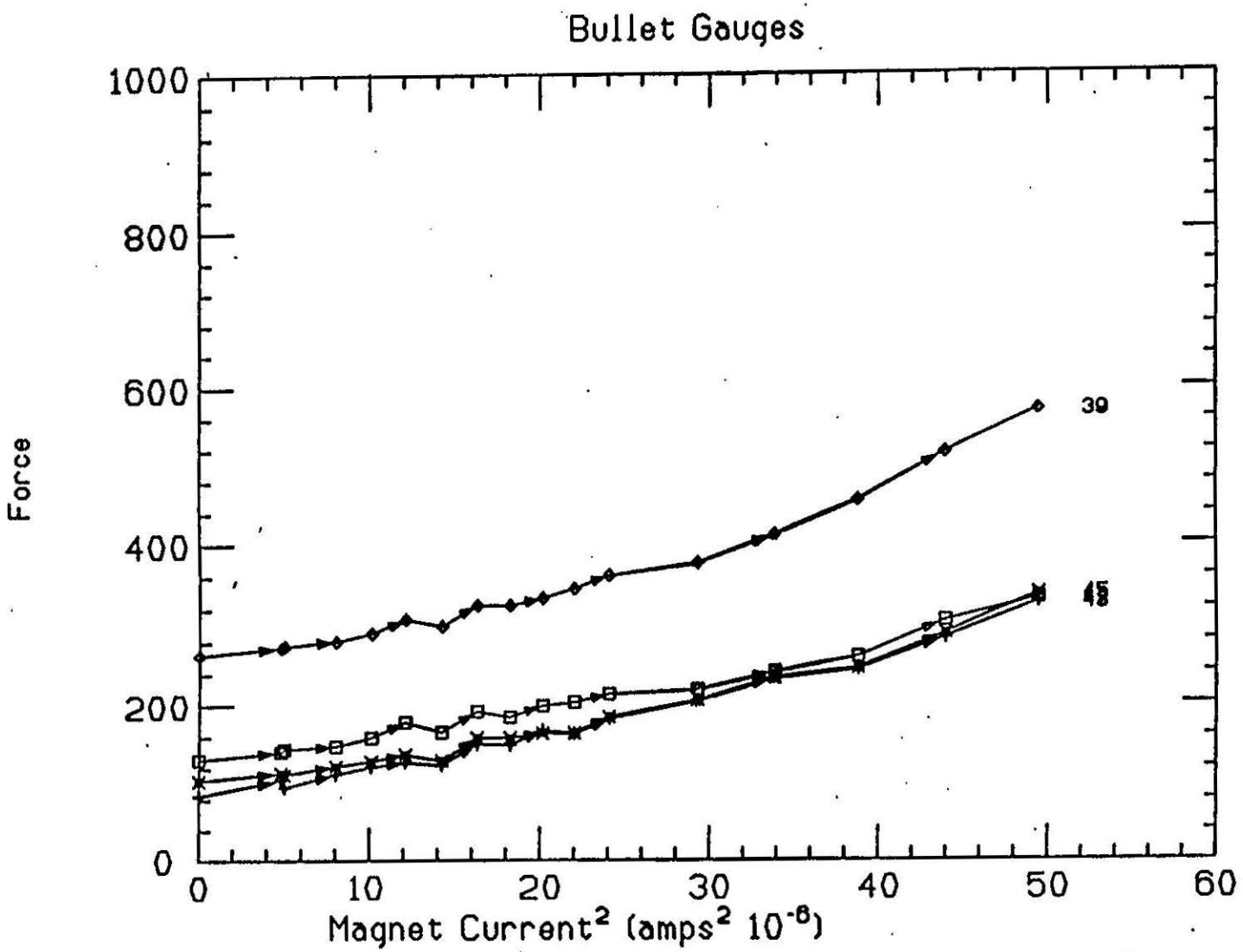




DSA321 File: DSA321.CA006 7-JAN-91 15:39:27 21-MAY-91 18:16:31



DSA324 File: DSA324.CA005 18-JUN-91 11:41:19 5-AUG-91 11:07:56



DSA323 File: DSA323.CA030 20-MAY-91 10:53:08 21-MAY-91 17:56:30

ALLOWED HARMONICS; LAB2 MAGNETOMETER

18 INCH ACTIVE LENGTH MORGAN COIL PROBE AVERAGE VALUE
AWAY FROM THE GAGE PACK (6" FROM CENTER TOWARDS RETURN END)

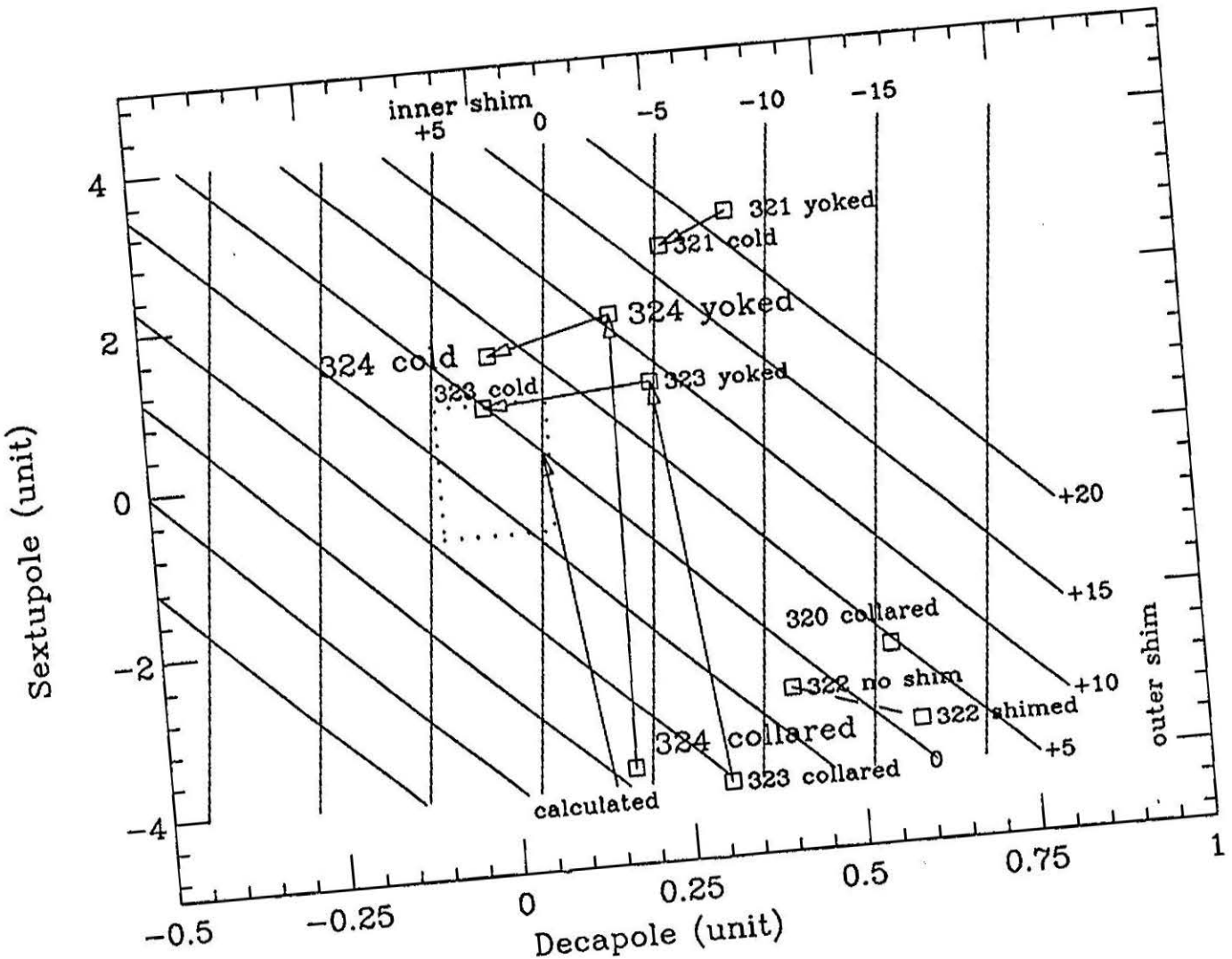
MAGNET	b2	b4
DSA323	.91	.23
DSA324	1.4	.002

TRANSFER FUNCTION FOR 50 mm MAGNETS (T/kA)

	DSA321	DSA323	DSA324	PREDICTED
Collared Coils ± 10 A	0.795	.794	.794	.795
Yoked ± 10 A	1.043	1.043	1.044	1.045
Cold at 5 kA	1.036	1.033	1.037	1.040

ROOM TEMPERATURE HARMONICS (UNITS @ 10 mm)

Pole	321	323	324	324 Ran.	SSC Sys.	SSC Ran.
b2	2.96	0.91	1.8	0.025	0.8	1.15
	±.12	±.06	±.08			
b4	0.36	0.23	0.18	0.029	0.08	0.22
	±.02	±.02	±.02			
b6	-0.07	-0.05	-0.04	0.007	0.01	0.02
	±.01	±.00	±.01			
b8	0.05	0.05	0.02	0.007	0.02	0.01
	±.01	±.00	±.02			
b10	0.02	0.02	0.02	0.001	–	–
	±.00	±.00	±.02			


inner shim
+5
0
-5
-10
-15
321 yoked
321 cold
324 yoked
324 cold
323 cold
323 yoked
+20
+15
+10
+5
0
320 collared
322 no shim
322 shimed
324 collared
323 collared
calculated
outer shim
Sextupole (unit)
Decapole (unit)
4
2
0
-2
-4
-0.5
-0.25
0
0.25
0.5
0.75
1

AC LOSS MEASUREMENTS --- INTRODUCTION

The objectives of these studies were :

- To study the AC losses of SSC model dipole magnets, under unipolar and bipolar ramp conditions

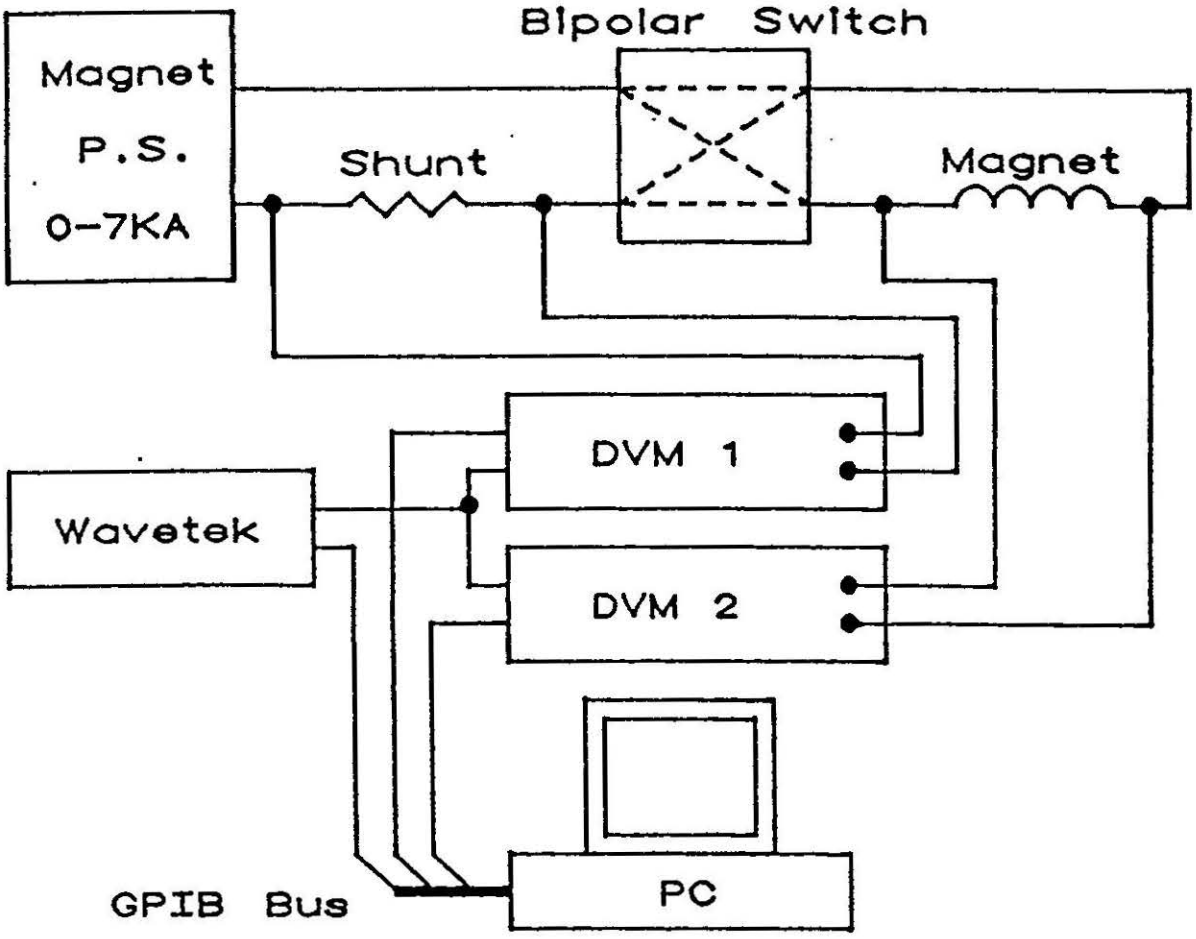
MEASUREMENT TECHNIQUE :

-IBM PC/AT BASED WITH "ASYST" DATA ACQUISITION SYSTEM WITH GPIB INTERFACE

-TWO HP3457A DVM'S SIMULTANEOUSLY READ SHUNT VOLTAGE AND MAGNET VOLTAGE (V_{MAG} AND I_{MAG})

- DVM'S ARE TRIGGERED SIMULTANEOUSLY USING TRIGGER PULSES FROM A DIGITAL WAVEFORM GENERATOR. NOMINAL TRIGGER RATE 4.5 HZ

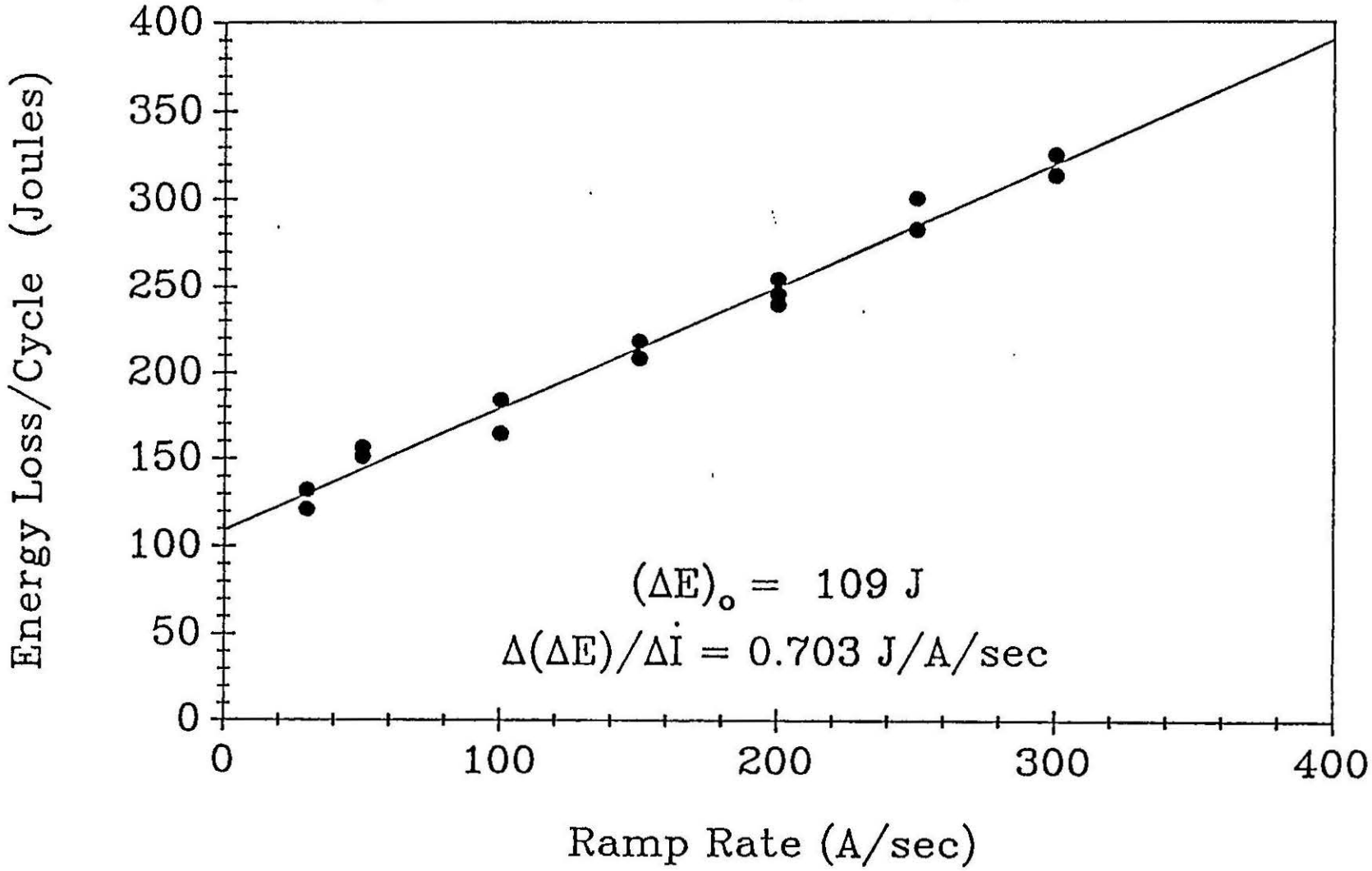
-VOLTAGES ARE RECORDED AS A FUNCTION OF TIME, UPLOADED TO MICROVAX AND ANALYZED

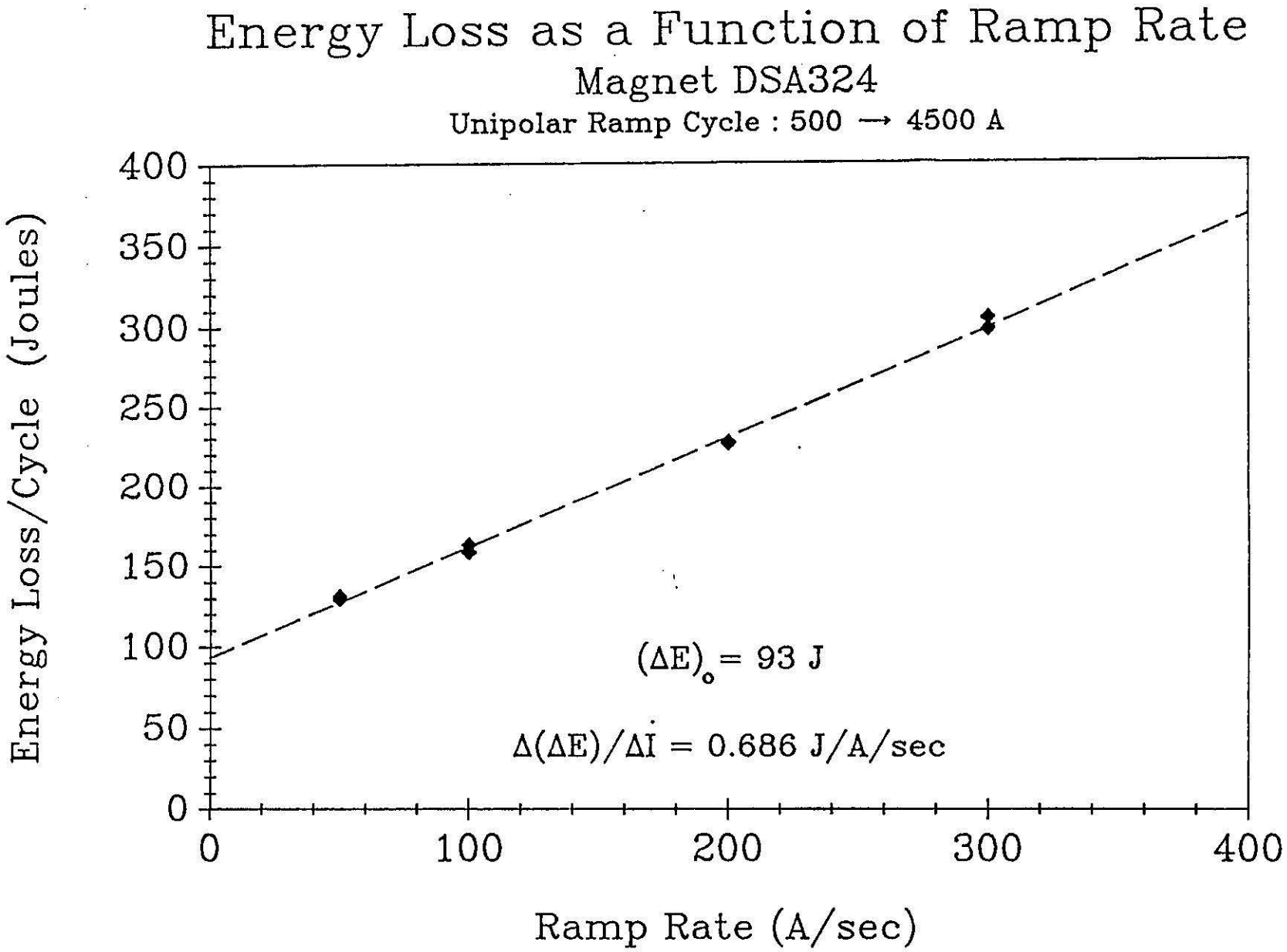

Bipolar Switch
Magnet
P.S.
0-7KA
Shunt
Magnet
DVM 1
Wavetek
DVM 2
PC
GPIB Bus

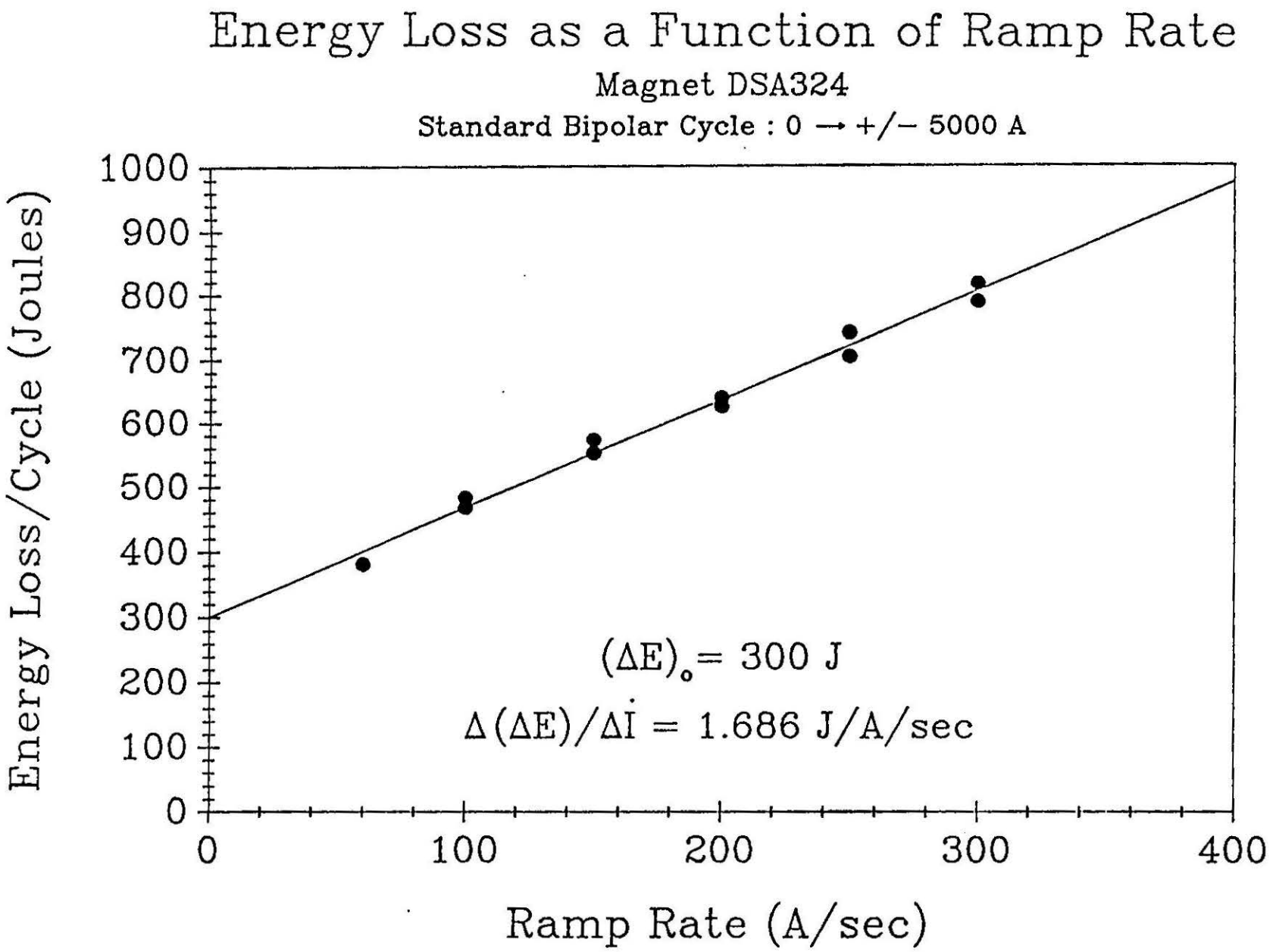
Energy Loss as a Function of Ramp Rate

Magnet DSA324

Standard Unipolar Ramp



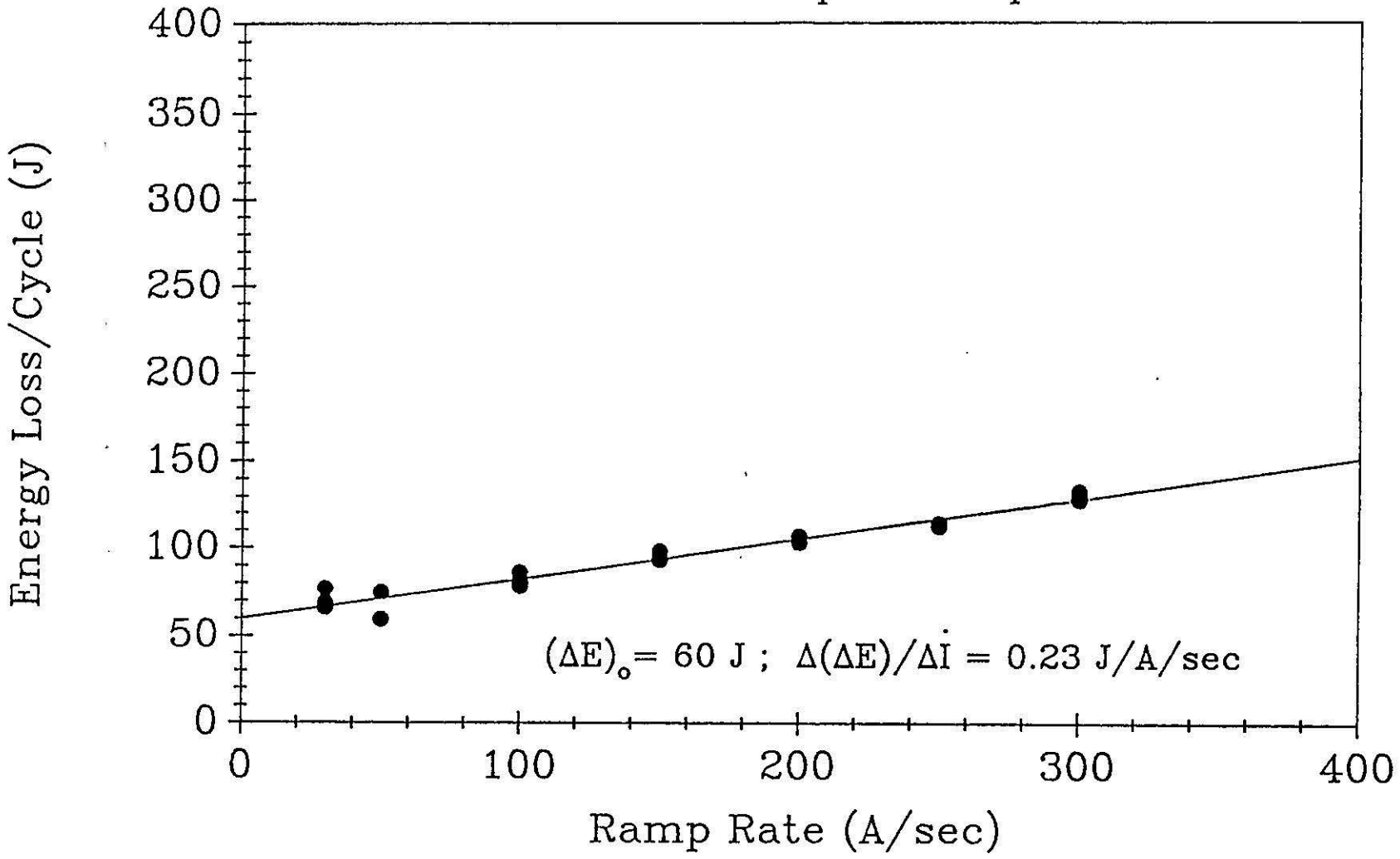

Energy Loss as a Function of Ramp Rate
Magnet DSA324
Unipolar Ramp Cycle : 500 → 4500 A
Energy Loss/Cycle (Joules)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
Ramp Rate (A/sec)
$(\Delta E)_o$ = 93 J
$\Delta(\Delta E)/\Delta I$ = 0.686 J/A/sec


Energy Loss as a Function of Ramp Rate
Magnet DSA324
Standard Bipolar Cycle : 0 → +/− 5000 A
Energy Loss/Cycle (Joules)
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
Ramp Rate (A/sec)
$(\Delta E)_o$= 300 J
$\Delta(\Delta E)/\Delta \dot{I}$ = 1.686 J/A/sec

Energy Loss as a Function of Ramp Rate

(Magnet DS0315)

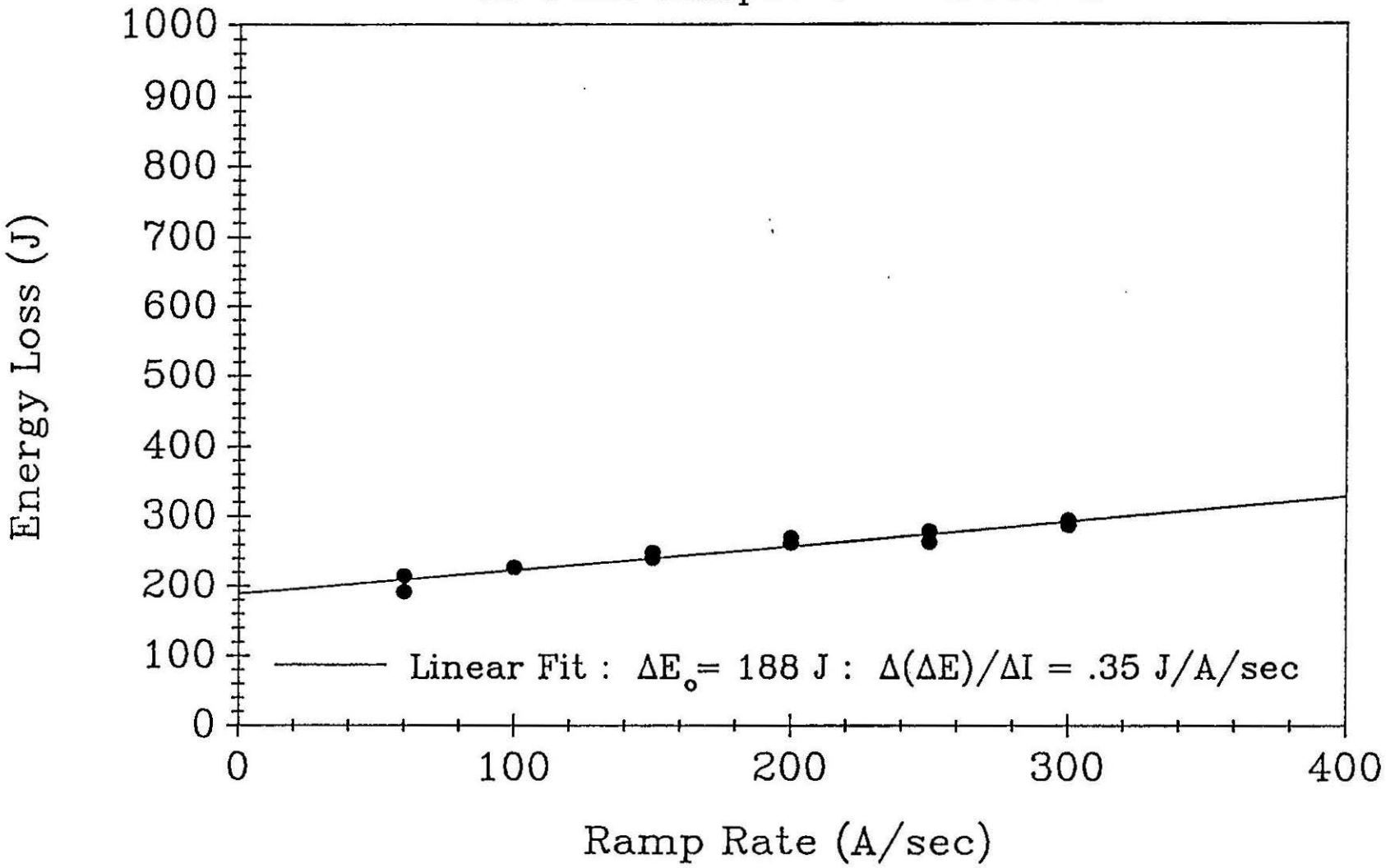
Standard Unipolar Ramp



Energy Loss as a Function of Ramp Rate

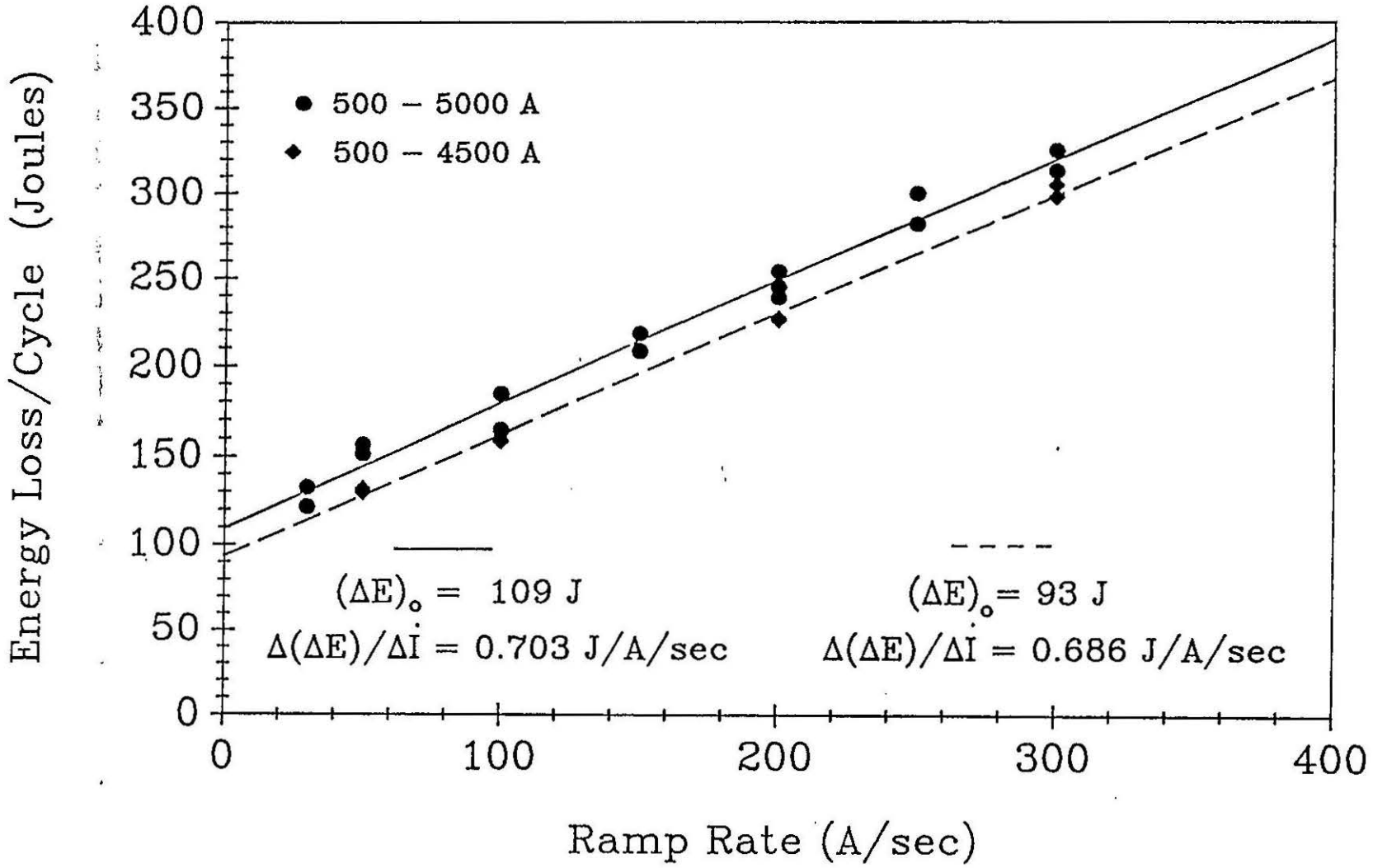
(Magnet DS0315)

Bi–Polar Ramps : 0 ⟶ ±5000 A



Energy Loss as a Function of Ramp Rate

Magnet DSA324



PERIODIC REMNANT FIELD STUDY ON 40 mm AND 50 mm SSC MODEL DIPOLES

LARGE AMPLITUDE PERIODIC REMNANT FIELD WAS OBSERVED IN 40 mm AND 50 mm APERTURE MAGNETS :

	Amplitude (Gauss) FLATTOP TIME AT 7000 A		
MAGNET	60 SEC	200 SEC	2000 SEC
DSA321	1.25	1.25	-
DS0315	0.4	-	-
DSA323	1.22	-	-
DSA324	2.52	2.0	4.2

LARGE AMPLITUDE SEEMS TO DEPEND UPON HOW LONG THE MAGNET IS AT HIGH CURRENT (7kA IN THIS CASE) . HOWEVER DSA321 DID NOT SHOW THIS BEHAVIOR .

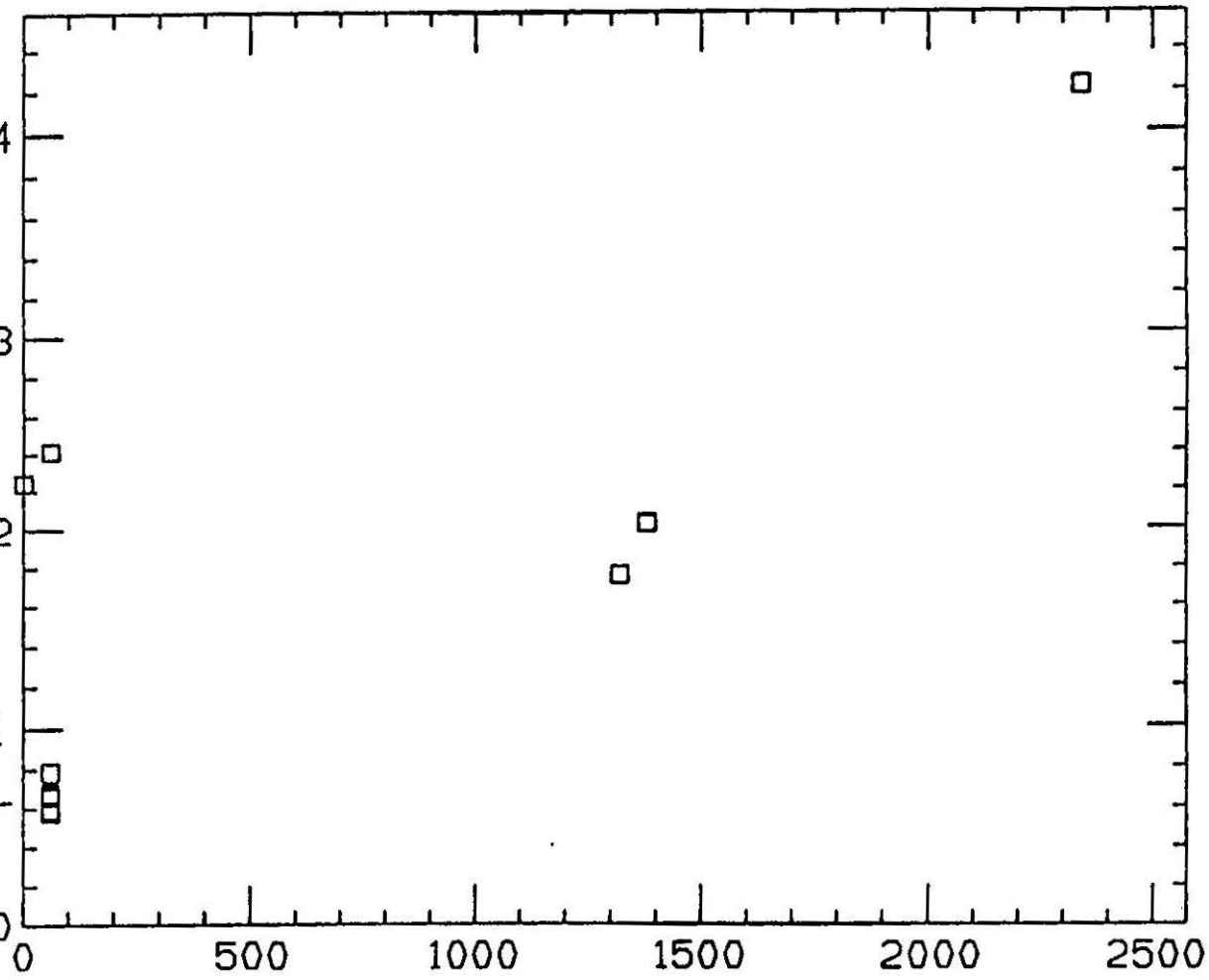
THE LARGE AMPLITUDE AND SMALL AMPLITUDE SIGNALS HAD PHASE DIFFERENCE OF 90 DEGREES .

THE DECAY BEHAVIOR OF (LARGE AND SMALL AMPLITUDE) REMNANT FIELD IS ALSO DIFFERENT .

ALL THIS NEEDS MORE DETAILED INVESTIGATION .

USING
RL 789 FIELD METER
Precision Rot. coil (6.35 mm)
output V ∝ Field
Hysteresis of S.C.

DSA324



Flattop	60 sec	200 sec
DS0315	0.40	
DSA321	1.25	1.25
S23	1.22	-
324	2.52	2.0

1 σ @ 2000 sec ≈ 4.2G

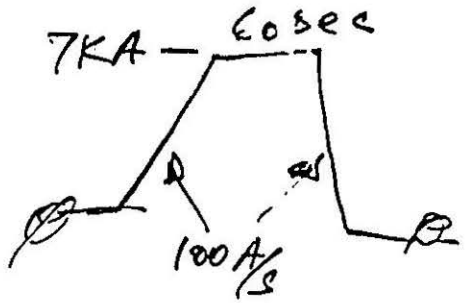
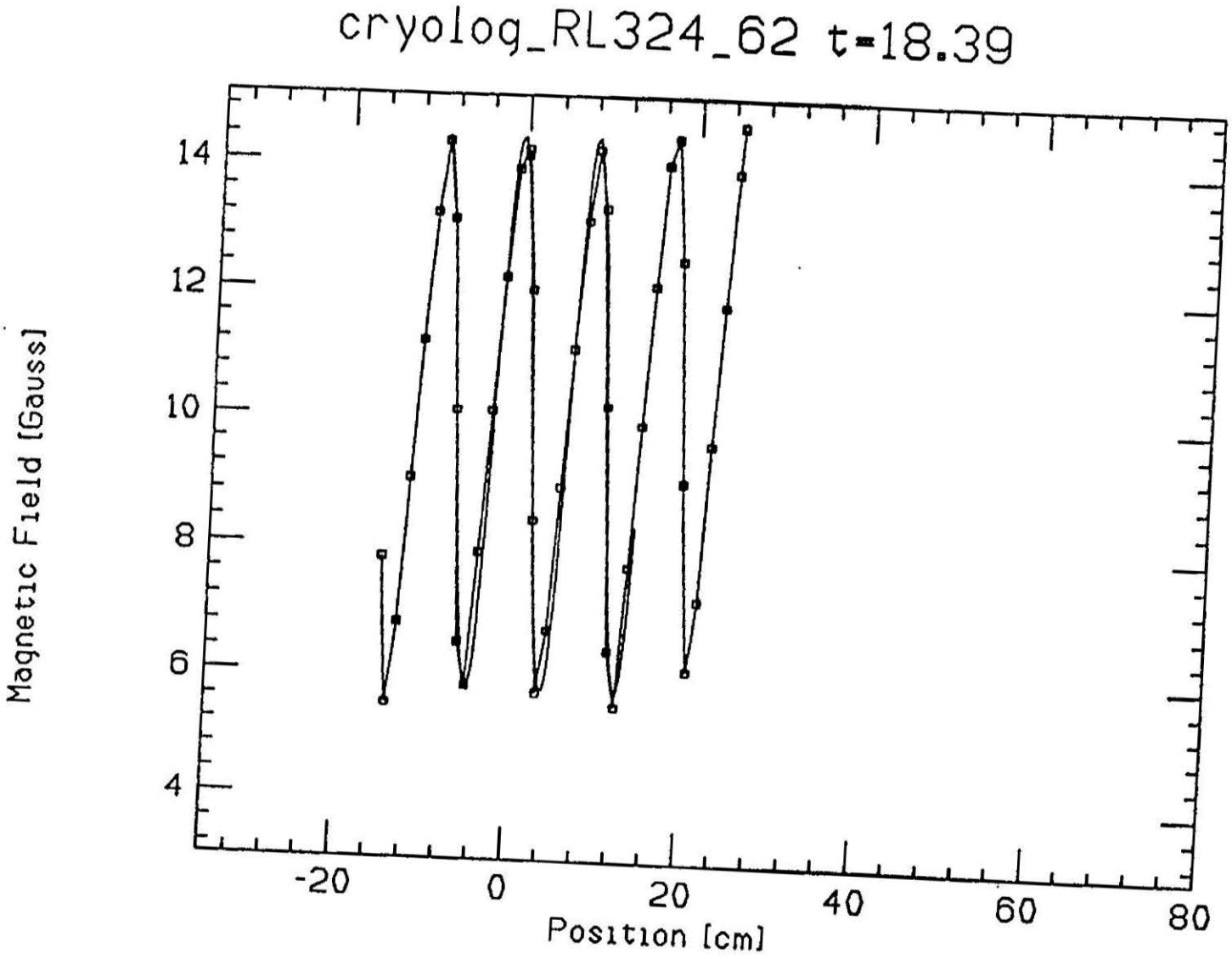


FIG 1

DSA324



Phase difference

DSA3.2.4

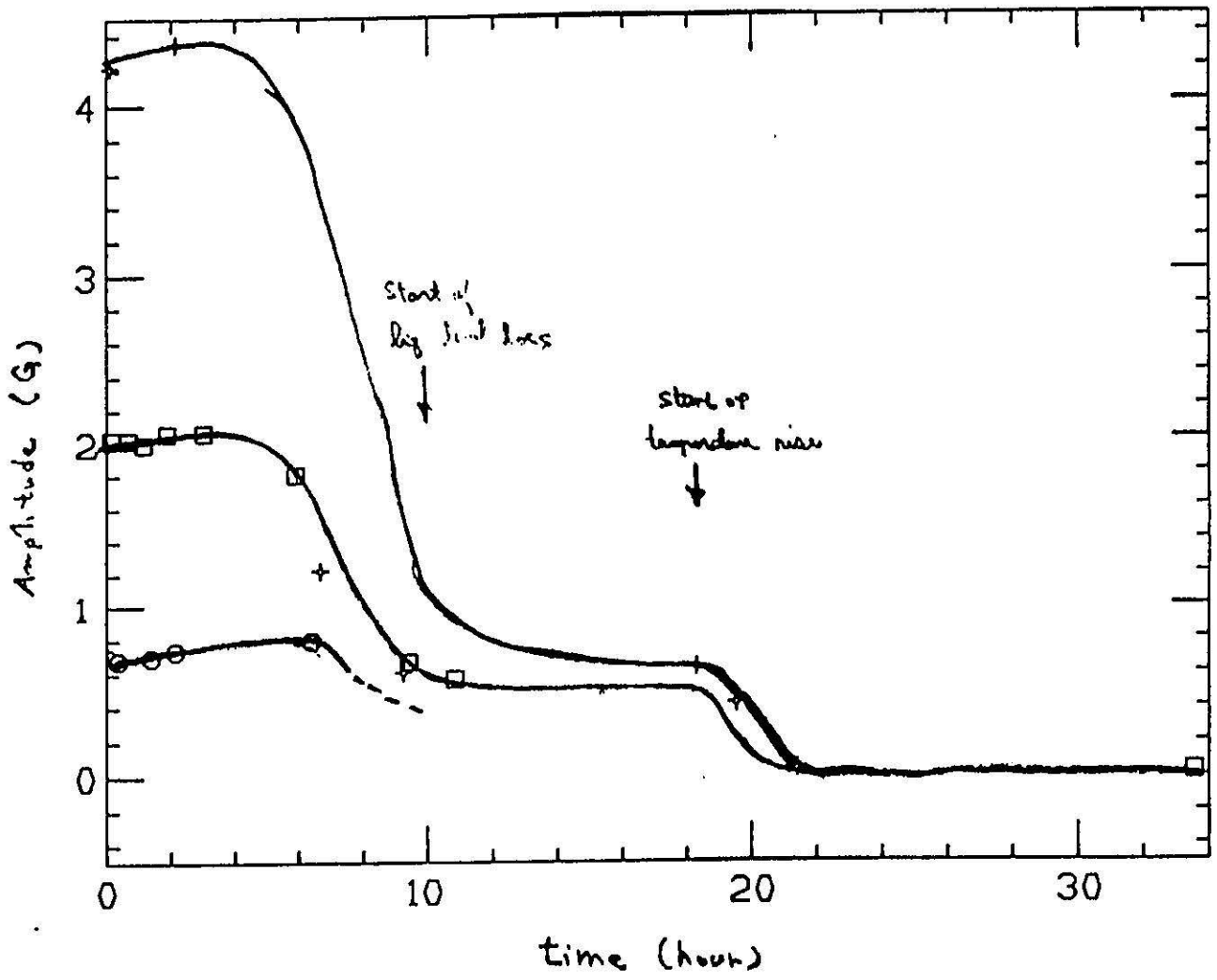
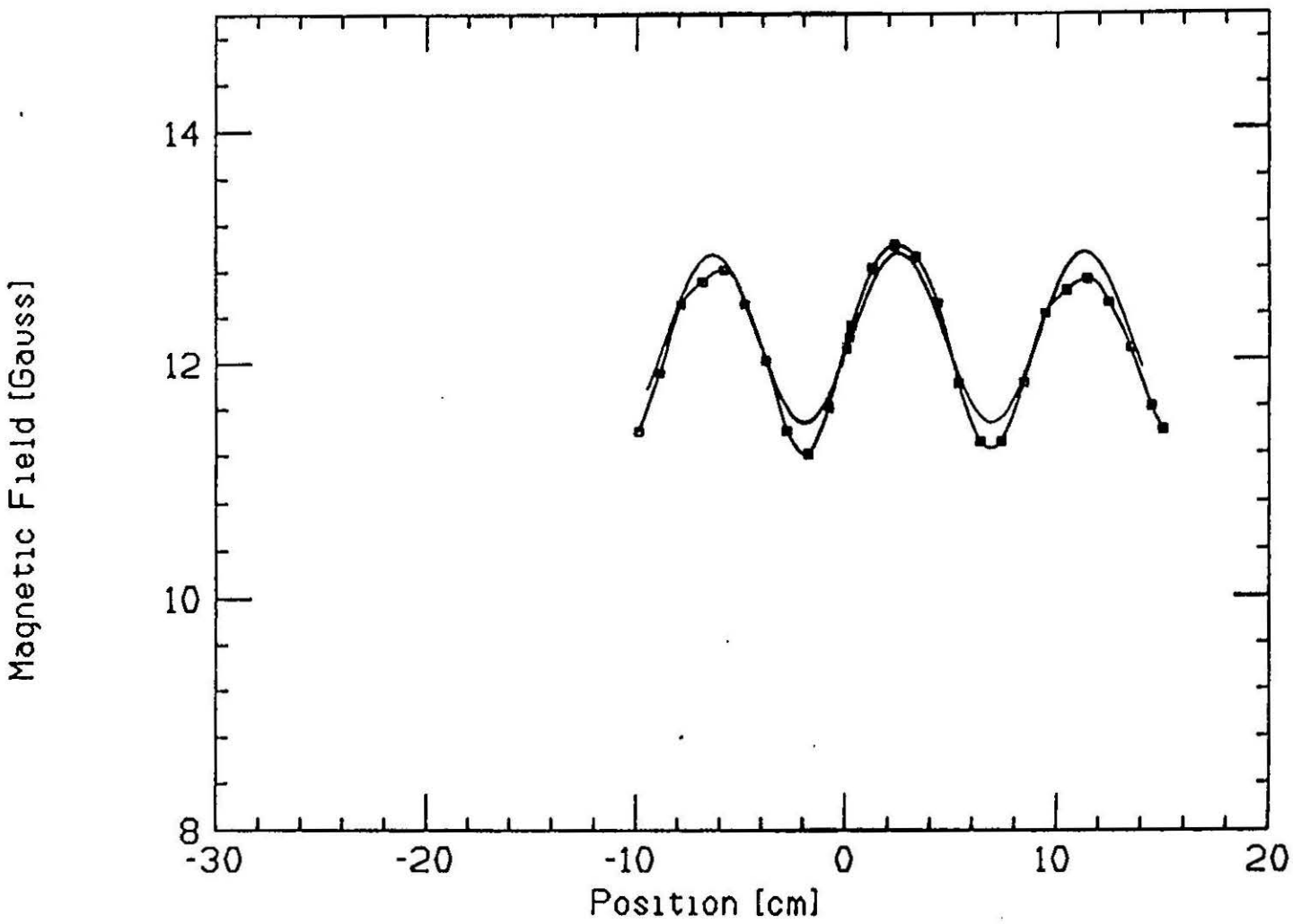


FIG 4

DECAY OF SIGNAL OVER TIME
LIQ LEVEL PART NOT INVESTIGATED YET



Strand pitch on SSC S.C ≈ 86 ± 5 mm.
on DSA321 wavelength ≈ 9.65 cm

Distribution:

FNAL
- R. Bossert
- J. Carson
- S. Delchamps
- S. Gourlay
- W. Koska
- M. Lamm
- P. Mantsch
- J. Strait
- M. Wake

SSCL
- A. Devred
- G. Pewitt (at FNAL)
- D. Smith