Fermilab

TS-SSC 92-087

Review of Fermilab Short Model Dipole Test Results

SSC Trailer Conference Room
Tuesday, October 27, 1992

9:00 - 9:30	Introduction and Overview	Jim Strait
9:30 - 9:45	Magnetic Design Change Due to Insulation Change	Jim Strait
9:45 - 10:30	Brief Review of Creep Studies	Dick Sims
10:30 - 11:00	Break	
11:00 - 111:45	Summary of Magnet Assembly Characteristics	Rodger Bossert
11:45 - 12:30	Mechanical Performance	Tariq Jaffery
12:30 - 2:00	Lunch	
2:00 - 2:30	Quench Performance (training)	Tariq Jaffery
2:30 - 3:00	AC Loss and Ramp Rate Dependency	Joe Ozelis
3:00 - 4:00	Field Quality: Warm Measurements Cold Measurements	Steve Delchamps Mike Lamm
4:00 - 4:30	Summary and Conclusion	Jim Strait

FNAL Short Magnet Program (FY92)

1) Evaluate alternate conductor insulation systems.
    - o Eliminate glass tape
    - o Maintain low cure temperature (≤150 C)

2) Evaluate alternate end part materials
    - o Injection molded
    - o RTM

3) Next iteration of "developable surface" end parts

4) Miscellaneous tests
    - o Rebuild DSA323 (down ramp quenching)
    - o Rebuild DSA329 (test effect of 2-piece pole end key)

~~5) Conductor placement studies~~ *Canceled*

Why change the insulation?

- Glass tape is perceived to cause shorts during coil manufacturing.

- A system which has a greater punch-through strength is desirable.

- Large friction between glass tape and mold cavity may result in a less uniform conductor azimuthal distribution.
  => Systematic shifts in the allowed harmonics.

- High cure temperatures (DuPont/BNL system) may enhance AC losses.

- High cure temperatures may require more expensive coil curing system or longer cure cycle.

- A thinner insulation system would allow cross-sections with higher current density to be designed.

  - Based on these considerations we chose to use a polyimide film with adhesive coated directly on its surface.

- Carl Says: epoxy (in glass tape) requires refrigeration
  => more elaborate quality control.

Insulation Development Program

1) Choose several insulation systems to test in magnets.
   - 10-stack studies of insulation creep.
   - test coils to set molding parameters.

2) Build 5 short magnets using 4 insulation systems.

3) Build 4 long magnets using 2 insulation systems.

4) Evaluate test results with respect to:
   - Assembly issues (ease of winding, cured coil integrity, etc.).
   - Pre-stress r~~elaxation~~. decrease with time
   - Field quality (agreement with calculations, reproducibility).
   - Quench performance.

Table I
Insulation Types Tested

Inner Wrap Film	Inner Wrap Over-lap	Inner Wrap Adhes.	Outer Wrap Film	Outer Wrap Over-lap	Outer Wrap Adhes.	Magnets	Designation in Table II and the Figures
H	50%	-	Glass	butt	epoxy	[a]	2H - |1FGe
H	50%	-	LT	butt	2290	[b]	2H - |1LT1e
NP	50%	-	NP	butt	2xCR	[c]	2NP- |1NP2c
NP	66%	CR	-	-	-	[d]	3NP1c|
H	50%	-	LT	butt	2x2290	[e]	2H - |1LT2e
H	50%	-	LT	50%	2290	[f]	2H - |2LT1e
NP	50%	-	NP	50%	2xCR	[g]	2NP- |2NP2c
NP	50%	CR	NP	50%	CR	[h]	2NP1c|2NP1c
H	50%	-	LT	50%	2x2290	[i]	2H - |2LT2e
NP	50%	-	NP	50%	CR	none	2NP- |2NP1c

Films

H = DuPont H-film Kapton
LT = DuPont LT-film Kapton
NP = Allied Signal NP-film Apical

Adhesives

2290 = 3M 2290 epoxy on one side
2x2290 = 3M 2290 epoxy on both sides
CR = Allied Signal Cryorad on one side
2xCR = Allied Signal Cryorad on both sides

Magnets
----
[a] Tevatron, HERA, ASST, UNK
[b] DSA330,332, DCA320,321 inner coils
[c] DSA334 DCA332,323 inner coils
[d] DSA331 inner coils
[e] DSA333 inner coils
[f] DSA330,332, DCA320,321 outer coils
[g] DSA334 DCA332,323 outer coils
[h] DSA331 outer coils
[i] DSA333 outer coils

Field Quality Issues

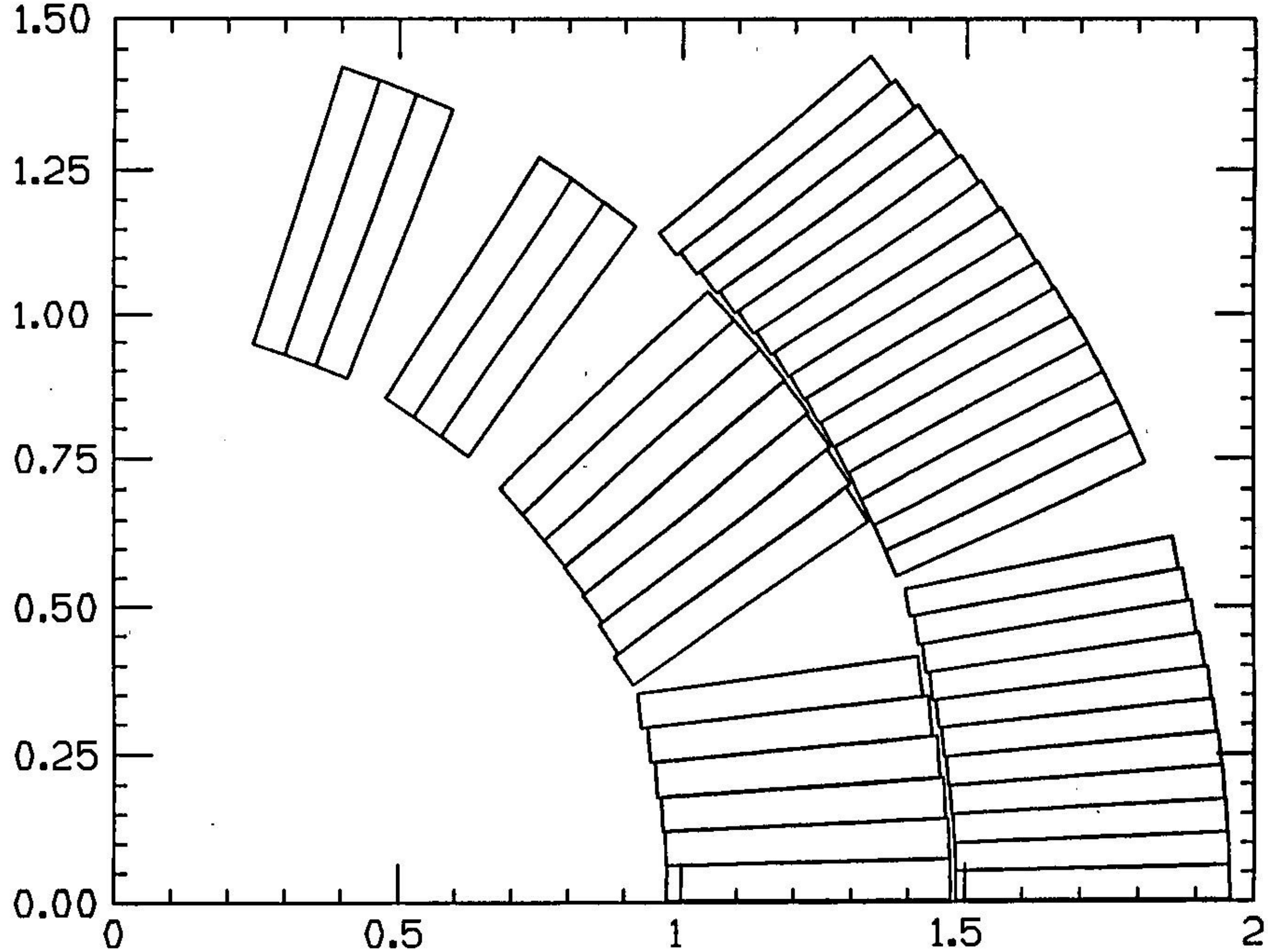
1) Thinner insulation
   => Wedge shims are used to keep the current blocks at the same average position to match the coil end parts.
      => Allowed harmonics change.

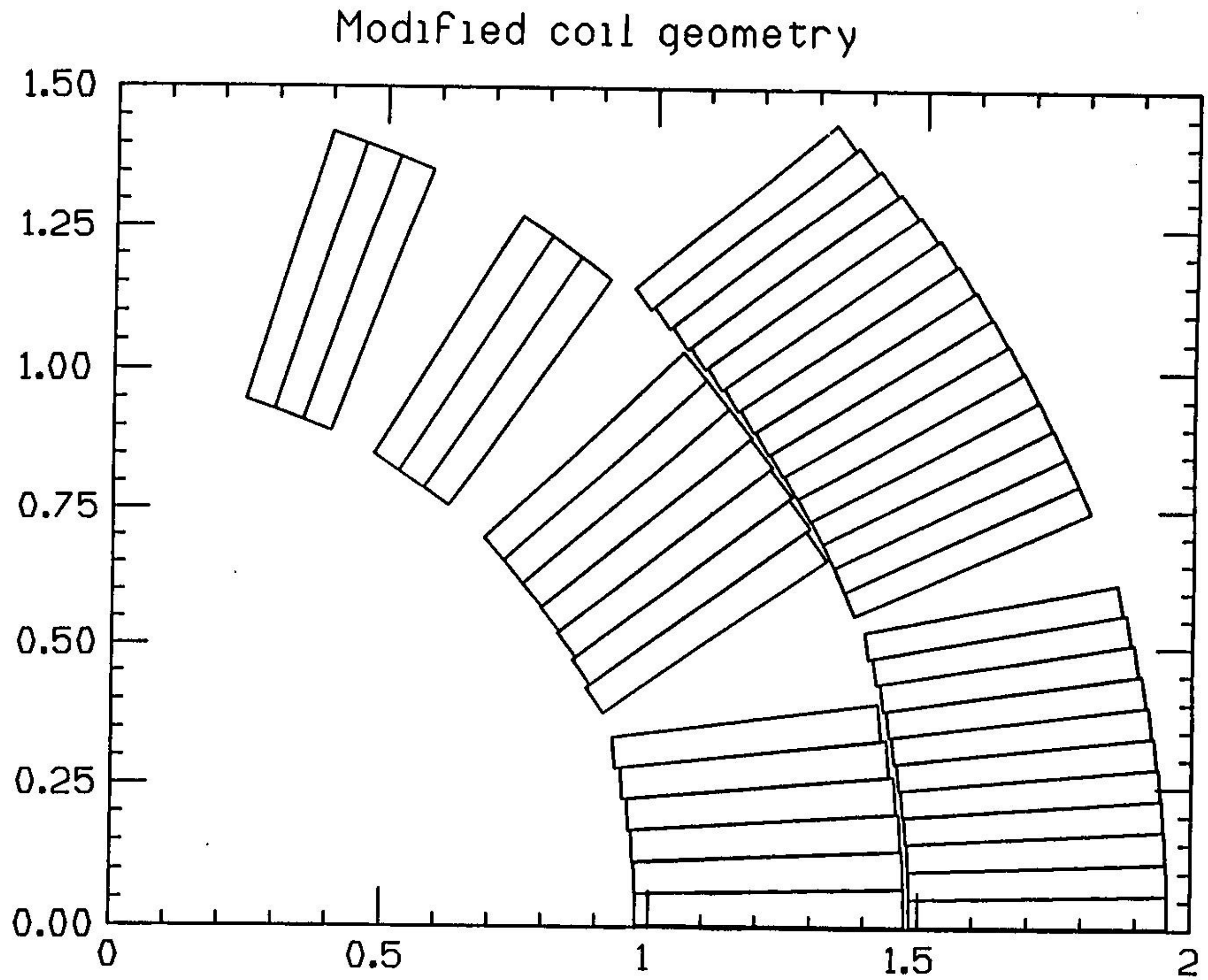
2) Insulation thickness varies a little among the insulation types, and the molding parameters are not perfectly known.
   => Pole shims (made of Kapton) are used, and are different from magnet-to-magnet.

3) It is **conjectured** that the lower friction in the mold will result in harmonics that are more reproducible and closer to the design values.

- However, corrections must be applied for pole shims before using the data to evaluate this hypothesis.

Original coil geometry




Modified coil geometry
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
0.5
1
1.5
2

Expected Harmonics with Thinner Insulation and Wedge Shims

(Calculations done by Akbar Mokhtarani,* using a program written by Allen Riddiford.)

	Original	New	Difference
b_2	0.23	2.14	+1.91
b_4	0.06	0.42	+0.36
b_6	-.024	0.039	+0.0~~36~~63
b_8	0.040	0.068	+0.028

* A. Mokhtarani, Effect of Reducing Cable Insulation on Harmonic Coefficients in 50 mm SSC Magnets, TS-SSC 92-028, 2/24/92

- **Warning:** The use of wedge shims and pole shims may compromise the quench performance:

  - Wedge shims are extended into the ends using several layers of Kapton tape, whose ends are staggered.
  - Pole shims are is some cases extended into the ends, but this was not always possible. (The shim thickness is not known until after the coil is molded, and often the pole-end key is too well bonded to the conductor insulation to allow the shim Kapton to be inserted.)
  - These may result in a mechanical discontinuity at the collar - end clamp boundary which may cause quenching.

CABLE INSULATION CREEP STUDIES REVIEW

by Richard E. Sims

at

Fermi National Accelerator Laboratory

October 27, 1992

Perceived disadvantages of Glass Tape System:

1. Breaks down at lower pressure (high voltage breakdown, BNL study).
2. Tears during winding - sharp corners on torn glass (usually requiring hand repair).
3. High friction in mold => Less uniform distribution of conductors and more size variation.
4. Larger epoxy volume => Hydraulically stretching Kapton can lead to insulation failure.
5. Limits current density. An all polyimide insulation wrap can permit lower insulation volume and allow an additional turn of superconductor.

Perceived disadvantages of eliminating Glass Tape:

1. Change cross-section. (Assumes minimum insulation approach).
2. Increases creep. Higher initial collaring forces would be required.
3. Reduced control of coil size variation from component size variation.
4. Lower modulus (but this may partially compensate for #3).
5. Larger thermal contraction.

Author: Perceived advantages of eliminating Glass Tape (assuming all Polyimide Film):

1. Greater high voltage breakdown in midplane.
2. Lower overall labor.
3. Although these experiments have shown that utilizing adhesive on every layer improves creep, microscopic studies reveal "adhesive leakage" onto cable strands. An optimum configuration may be to utilize adhesive on both sides of the outer layers of insulation with no adhesive on the inside layers of insulation (per contribution by Amanda Spindel.)

COMPARISON OF POLYIMIDE FILM DATA

All data on 1 mil thick film unless noted

RICHARD E. SIMS   February 4, 1992

Physical Properties	Dupont HN Typical Values	HN Test Conditions	Dupont H	Dupont HA	Dupont LT	Allied (Apical) AV	Allied (Apical) NP	Dupont 120 CT-1	Dupont 135 RCI
Physical Properties at (Temp.)	23° C (73°F)	200°C (392°F)	23°C	23°C	23°C	23°C	23°C	23°C, 1.2 Mil	23°C, 1.35 Mil
Ultimate Tensile (MD) Strength, MPa (psi) (36.000)	231 (33,500)	139 (20,000)	(32 K psi)	(31 K psi)	(24 K psi)	(35 K psi)	(44 K psi)	(30 K psi)	(20 K psi)
Yield Point (MD) at 3%, MPa (psi)	69 (10,000)	41 (6,000)				(10,000)			
Stress to Produce (MD) 5% Elongation, MPa (psi)	90 (13,000)	61 (9,000)				(13,000)			
Ultimate Elongation (MD),%	72	83	70	83	80	95	90	85	65
Tensile Modulus, GPa (MD) (psi)	2.5 (370,000)	2 (290,000)	(400,000)	(310,000)	(500,000)	2.92 (460,000)	4.26 (600,000)	(350,000)	(475,000)
Impact Strength, Kg-cm (ft-lb)	8(.58)								
Folding Endurance (MIT), cycles	285000			>1,000,000		>1,000,000	>150,000		
Tear Strength (MD)-Propagating (Elmendorf),g	7		16	35		8	7		
Tear Strength (MD) - Initial (Graves),g	729					520	600		
Density, g/cm3	1.42					1.42	1.45		
Coefficient of Friction - Kinetic (Film-to-Film)	0.48					0.40			
Coefficient of Friction - Static (Film to Film)	0.63					0.5			
Refractive Index (Becke Line)	1.66								
Poisson's Ratio	0.34								
Low Temperature Flex Life	Pass								
Dielectric Constant		3.4				3.4	3.3	3.5	3.8
Dielectric Strength V/Mil		7,700		6500	3500	7800	8000	6000	4500

NOTE: All information supplied by the manufacturers.

SUMMARY OF SSC-FNAL COIL INSULATIONS

DATE: 11-21-91

R. E. SIMS

TYPE	H	H	H+ 2290	HA	LT+ 2290	HA	LT+ 2290
MANUFACTURERS' DESIGNATION			120EC	100HA	120REC 100REC	200HA	220REC
FILM THICKNESS (INCHES)	0.0005	0.001	0.001	0.001	0.001	0.002	0.002
ADHESIVE THICKNESS (INCHES)	NONE	NONE	.0001 - .0002	NONE	.00015 - .00025	NONE	.00015 - .00025
FINAL STOCK		YES		448K	350K		
ON ORDER (FEET)	150K		100K			100K	100K
FINAL STOCK #	MA-292590			MA-292586	MA-2922587	MA-292~~589~~ 588	MA-292589

TYPE	AV	NP	AV+ CRYORAD	NP+ CRYORAD	AV+ 2290	NP+ 2290
MANUFACTURERS' DESIGNATION	100AV	100NP	CRYOWRAP 210V	CRYOWRAP 210P	210VM	210PM
FILM THICKNESS (INCHES)	0.001	0.001	0.001	0.001	0.001	0.001
ADHESIVE THICKNESS (INCHES)	NONE	NONE	.00020 - .00025	.00020 - .00025	.00020 - .00025	.00020 - .00025
FINAL STOCK						
ON ORDER (FEET)	300K	111K	300K	300K	100K	100K
FINAL STOCK #	MA-292717	MA-292718	MA-292713	MA-292716	MA-292714	MA-292715

MEMORANDUM

TO: R. BOSSERT, J. CARSON, J. STRAIT, F. NOBREGA, E. G. PEWITT
M. WAKE, P. SCHMIDT, A. SPINDEL

FROM: R. E. SIMS

DATE: 12-05-91

SUBJECT: DETAILED 10-STACK EXPERIMENT PLAN (Revision 2)

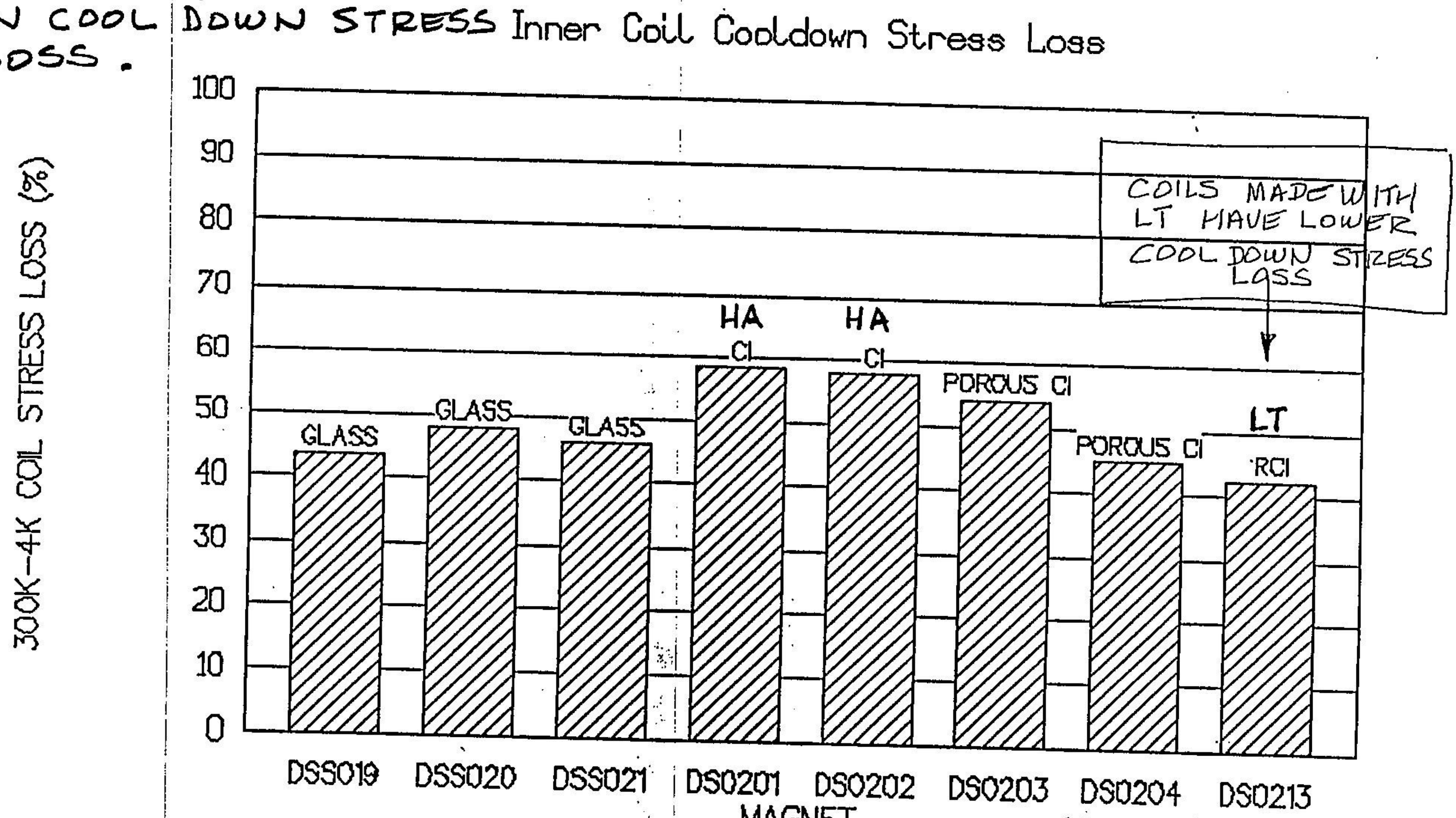
OPERATION	DATE	INNER INSULATION OVERLAP, TYPE	OUTER INSULATION OVERLAP, TYPE	MOLD PRESSURE PSI	STACK LABEL ETC.
10-STACK MOLD RUN	11/7 - 11/15	50% KAPTON H	BUTT, GLASS	10K - 4K	GT #6 (20% EPOXY)
		50% KAPTON H	BUTT, GLASS	8K - 4K	GT #7 (10% EPOXY)
		50% KAPTON H	BUTT, GLASS	8K - 3K	GT #4 (20% EPOXY)
		50% KAPTON H	BUTT, GLASS	4K - 3K	GT #5 (20% EPOXY
		50% KAPTON H	BUTT GLASS	10K PSI - CONST.	GT #8 (10% EPOXY)
		50% KAPTON H	BUTT GLASS	6K PSI - CONST.	GT #9 (10% EPOXY)
		BARE CABLE		10K - 4K	BARE #1
		BARE CABLE		6K - 3K	BARE #3
		BARE CABLE		10K CONT.	BARE #2 (RE-TAKE)
		STEEL MASTER	HEAT RUN FOR FIXTURE CALIBRATION	10000 - 4K	SM #1
		66% KAPTON H	50%, H+2290	10,000	H #1
		66% KAPTON H	50%, H+2290	6,000	H #2
		50% KAPTON H	BUTT, H+2290	10,000	
		50% KAPTON H	BUTT, H+2290	6,000	
		STEEL MASTER		6,000	SM
2-HOUR CREEP MEASUREMENTS	11/25 - 12/4	ALL ABOVE STACKS			
	11/21 - 12/02	50% KAPTON HA	BUTT, KAPTON LT	10,000	HA 50-1, HA 50-2
		50% KAPTON HA	BUTT, KAPTON LT	6,000	HA 50-3
		66% KAPTON HA	BUTT, KAPTON LT	10,000	HA #2 (HA #1, BAD)
		66% KAPTON HA	BUTT, KAPTON LT	6,000	HA #3
2-HOUR CREEP MEASUREMENTS	12/4 - 12/10	ABOVE 4 STACKS			
REVIEW DATA	12/12	CHOOSE "OPTIMIZED" KAPTON SYSTEM			
10-STACK MOLD RUNS	12/10 - 12/26	50% APICAL AV	BUTT, APICAL NP+2290	10,000	
		50% APICAL AV	BUTT, APICAL NP+2290	6,000	
		50% APICAL AV	BUTT, APICAL NP +CRYORAD	10,000	
		50% APICAL AV	BUTT, APICAL NP +CRYORAD	6,000	
	OPTIONAL	66% APICAL AV	BUTT, APICAL NP +CRYORAD	10,000	
	OPTIONAL	66% APICAL AV	BUTT, APICAL NP +CRYORAD	6,000	
2-HOUR CREEP MEASUREMENTS	12/9 - 12/11	ALL ABOVE STACKS WITH APICAL			
EVALUATE ALL ABOVE RESULTS	12/12 - 12/20	POSSIBLY RUN OTHER STACKS AS A RESULT OF EVALUATION			

* COMPARE TO BNL, RUN RCI 10-STACKS

**ADD HI TEMP. POLYIMIDE ADHESIVE 10-STACKS

UPON FURTHER CONSIDERATION IT WAS DECIDED THAT THE (APROX.) 22% LOADING OF THE "LT" KAPTON WOULD ONLY RESULT IN A (APROX.) 7% REDUCTION IN COOL DOWN STRESS LOSS.

1.8m, 4cm SSC MAGNET DATA



REASON FOR FAVORING LT (LOADED POLYIMIDE) FILM AS THE UPPER LAYER(S) OF INSULATION

FROM
M. ANERELLA
BNL
8-6-91

APICAL BRAND INSULATION COMBINATIONS BEING STUDIED AS TEN STACKS

MATERIAL INNER	MATERIAL OUTER	WRAP PATTERN(IN/OUT) 2/1	2/2	3/1	3/2	LAYER ADHESIVE INNER	LAYER ADHESIVE OUTER	
AV	NP	(X)		6K 10K (X)	X		C	BEST ELONG + TOUGH COVER
AV	NP*	X	X				E	" " " "
NP	NP	6K 10K (X)	(X) 10K				C	TOUGHEST INNER + OUTER
NP	NP	10K (X)				C	C	TEST LAYER TO LAYER GLUE
NP*	NP*	X	X				E	COMPARES CRYORAD AND EPOXY
NP	LT	10K (X)	(X) 10K				E	TOUGHEST WITH BEST CRYO
AV	LT	10K (X)				C	E	LIKE DUPONTS HA + LT BUT BOTH LAYERS BONDED
INNER COILS		↑	↑ NEEDED	FOR OUTER COILS				
NP	LT	(X)	X			C	E	BEST CREEP + CRYO SHRINK?

AV= APICAL BRAND POLYIMIDE FILM WITH TENSILE MODULUS OF 460 KPSI , 1.0 MILS THICK
NP= APICAL BRAND POLYIMIDE FILM WITH TENSILE MODULUS OF 600 KPSI, 1.0 MILS THICK
C= CRYORAD BRAND ADHESIVE, 0.15 TO 0.25 MILS THICK
E= #2290 EPOXY FROM 3M, 0.15 TO 0.25 MILS THICK

COATED FILMS ARE IDENTIFIED AS FOLLOWS:

MFG.#	FNAL #	BASE FILM	ADHESIVE
100AV	MA-292717	1 MIL. AV	NONE
100NP	MA-292718	1 MIL. NP	NONE
210V	MA-292713	1 MIL. AV	0.2 MIL CRYORAD
210P	MA-292716	1 MIL. NP	0.2 MIL CRYORAD
210VM	MA-292714	1 MIL. AV	0.2 MIL 2290 EPOXY
* 210PM	MA-292715	1.MIL. NP	0.2 MIL.2290 EPOXY

* MATERIAL IS UNAVAILABLE

R.E.SIMS
1-16-91

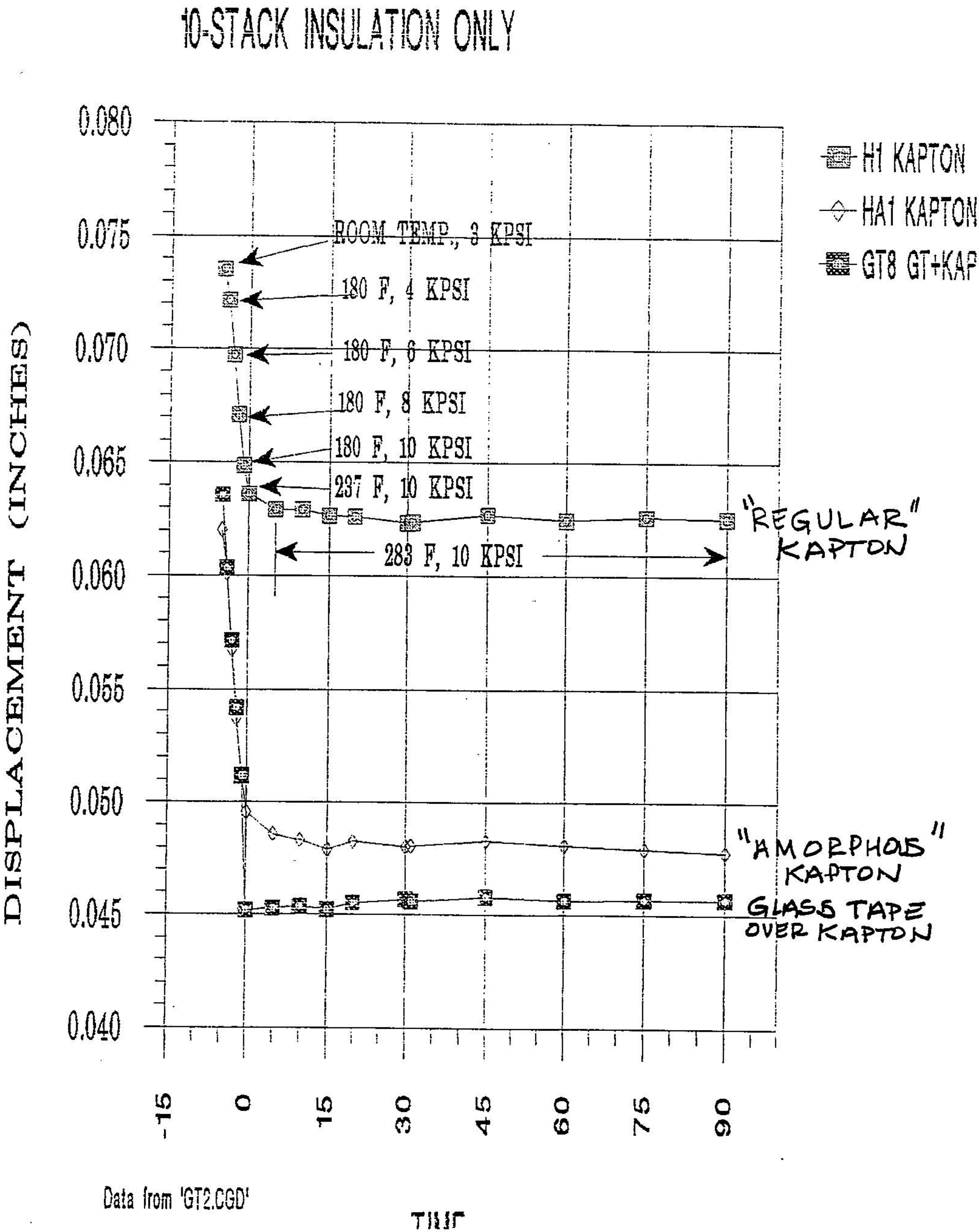
10-STACK CURING AND MEASURING PROCEDURE

STACK #	DATE:	BY:

DESCRIPTION OF STACKS

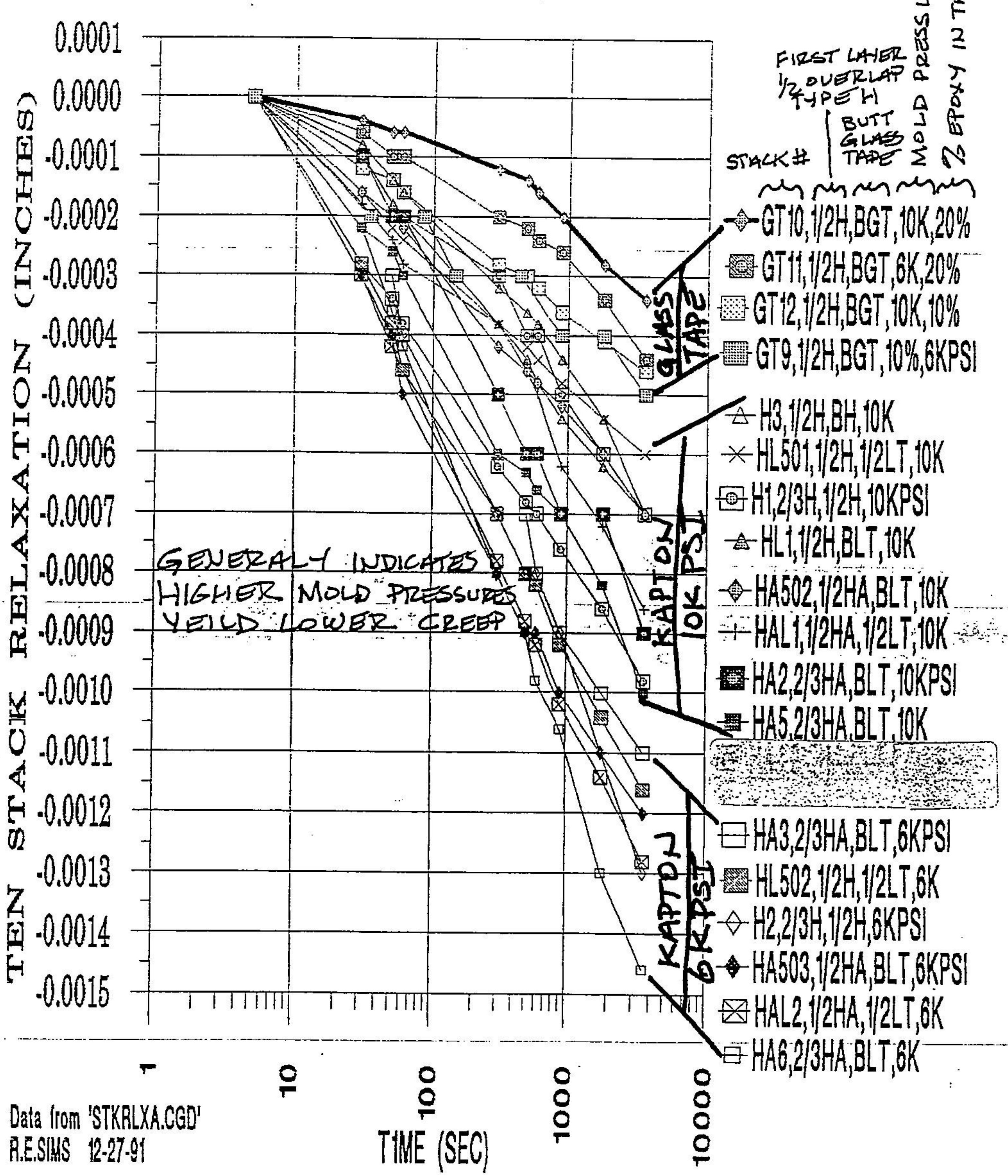
OPERATION	TEMPERATURE F	LINE PRESSURE PSI	RECORD DISPLACEMENT (INCHES)
Place Steel Master in press,			
Raise pressure & zero the probe.	Room	1627 (3000)	"1.0000"
Raise pressure & Record	Room	2170 (4000)	
Raise pressure & Record	Room	3254 (6000)	
Raise pressure & Record	Room	4340 (8000)	
Raise pressure & Record	Room	5424 (10,000)	
Raise pressure & Record	Room	6508 (12,000)	
Drop pressure & Remove Steel Master			
Place 10-Stack in Press			
Raise Pressure & Record	Room	1627 (3000)	- 5 sec
Raise Temperature & Record	180 F		
Raise Pressure & Record		2170 (4000)	-4 sec
*Optional: Raise Pressure & Record		3254 (6000)	-3 sec
*Optional: Raise Pressure & Record		4340 (8000)	-2 sec
*Optional: Raise Pressure & Record		5424 (10,000)	-1 sec
*Optional: Raise Pressure & Record		6504 (12,000)	
Start counting "Cure Time" when temp. exceeds 237 F			
Continue Raising temp. to	265 F		0 sec
Displacement as follows: 5 Minutes			
10 Minutes			
15 Minutes			
20 Minutes			
30 Minutes			
31 Minutes/Lower Pressure			
45 Minutes			
60 Minutes			
75 Minutes			
90 Minutes			
105 Minutes/Heater off, Cooler on			
120 Minutes			
135 Minutes			
150 Minutes			

ALLOW TEMPERATURE TO LOWER
TO BELOW 120 F AND RELEASE
PRESSURE. REMOVE 10-STACK
AND MARK THE STACK WITH

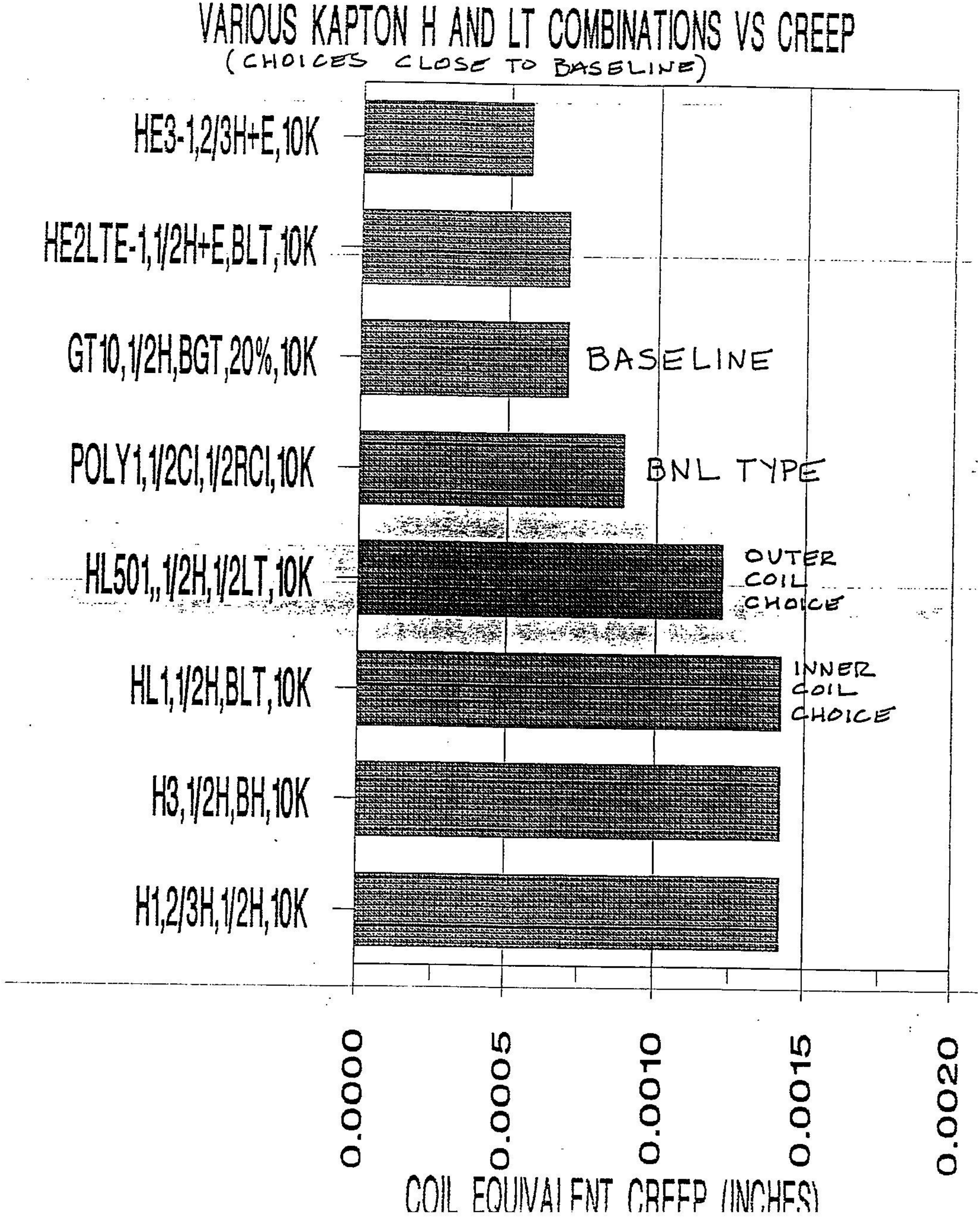


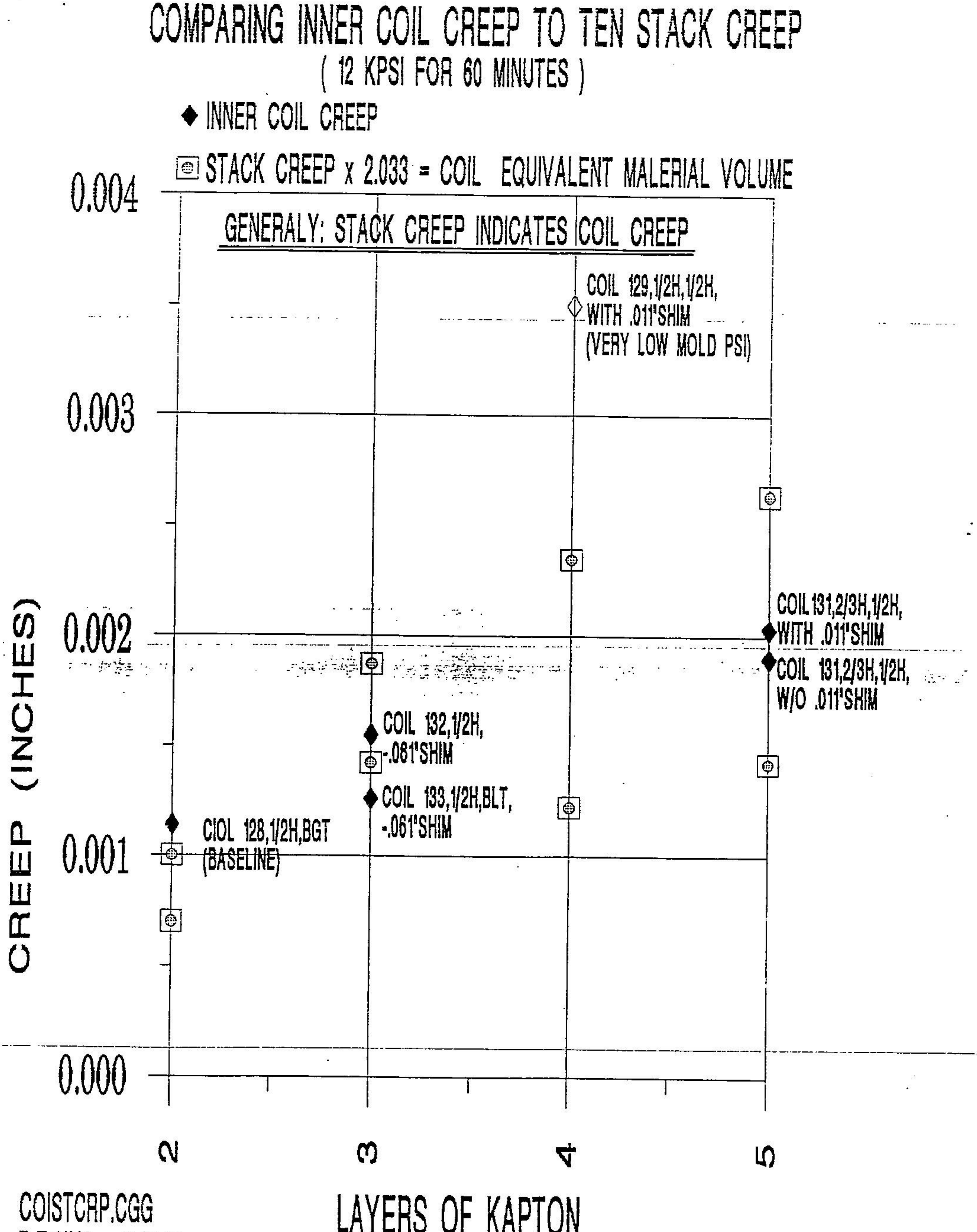
10-STACK INSULATION ONLY
DISPLACEMENT (INCHES)
0.080
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
H1 KAPTON
HA1 KAPTON
GT8 GT+KAP
ROOM TEMP., 3 KPSI
180 F, 4 KPSI
180 F, 6 KPSI
180 F, 8 KPSI
180 F, 10 KPSI
237 F, 10 KPSI
283 F, 10 KPSI
"REGULAR" KAPTON
"AMORPHOS" KAPTON
GLASS TAPE OVER KAPTON
-15
0
15
30
45
60
75
90
Data from 'GT2.CGD'
TIME

TEN STACK STRESS RELAXATION WITH 12 KPSI FOR ONE HOUR (SSC 50mm INNER CABLE)

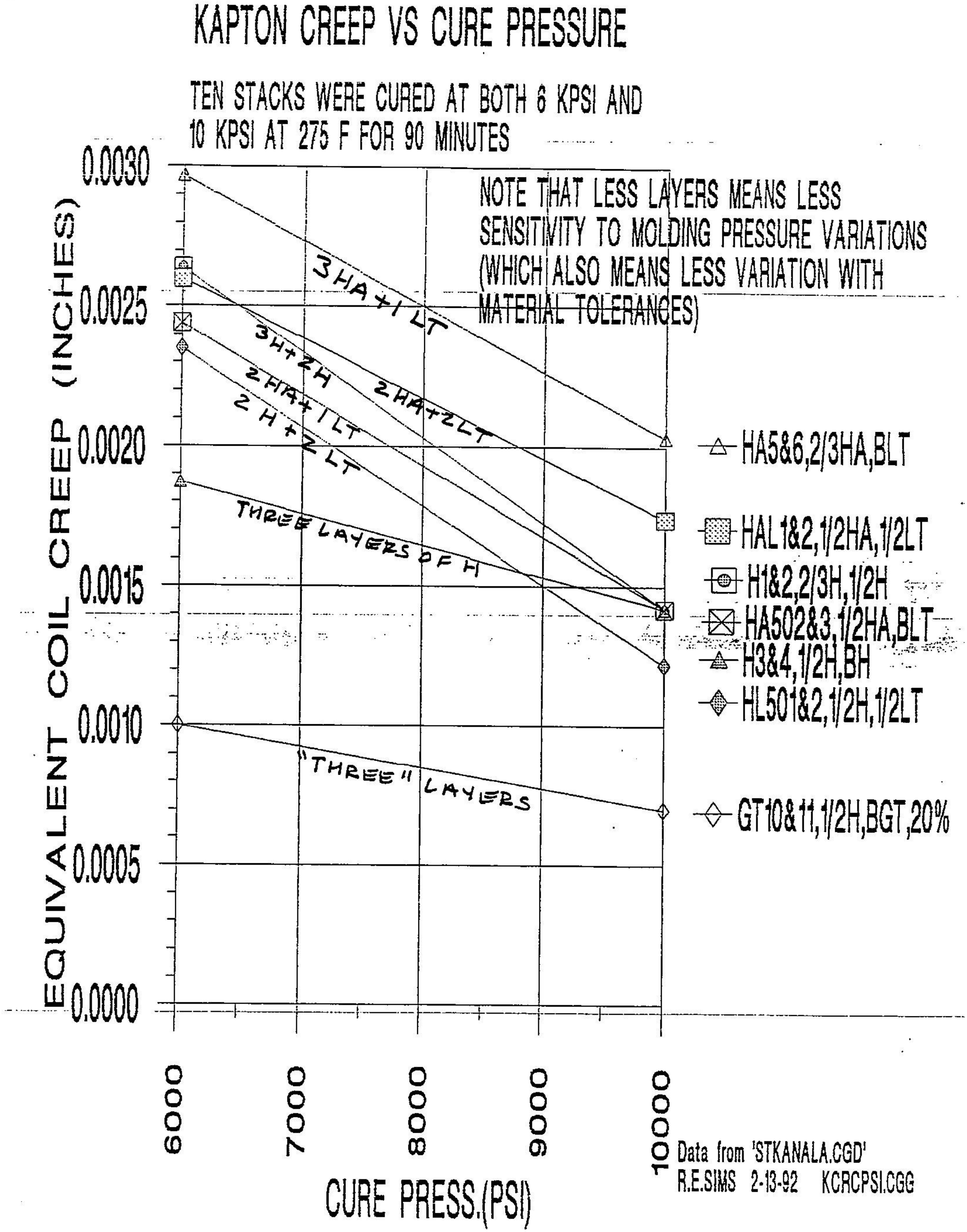


Data from 'STKRLXA.CGD'
R.E.SIMS 12-27-91

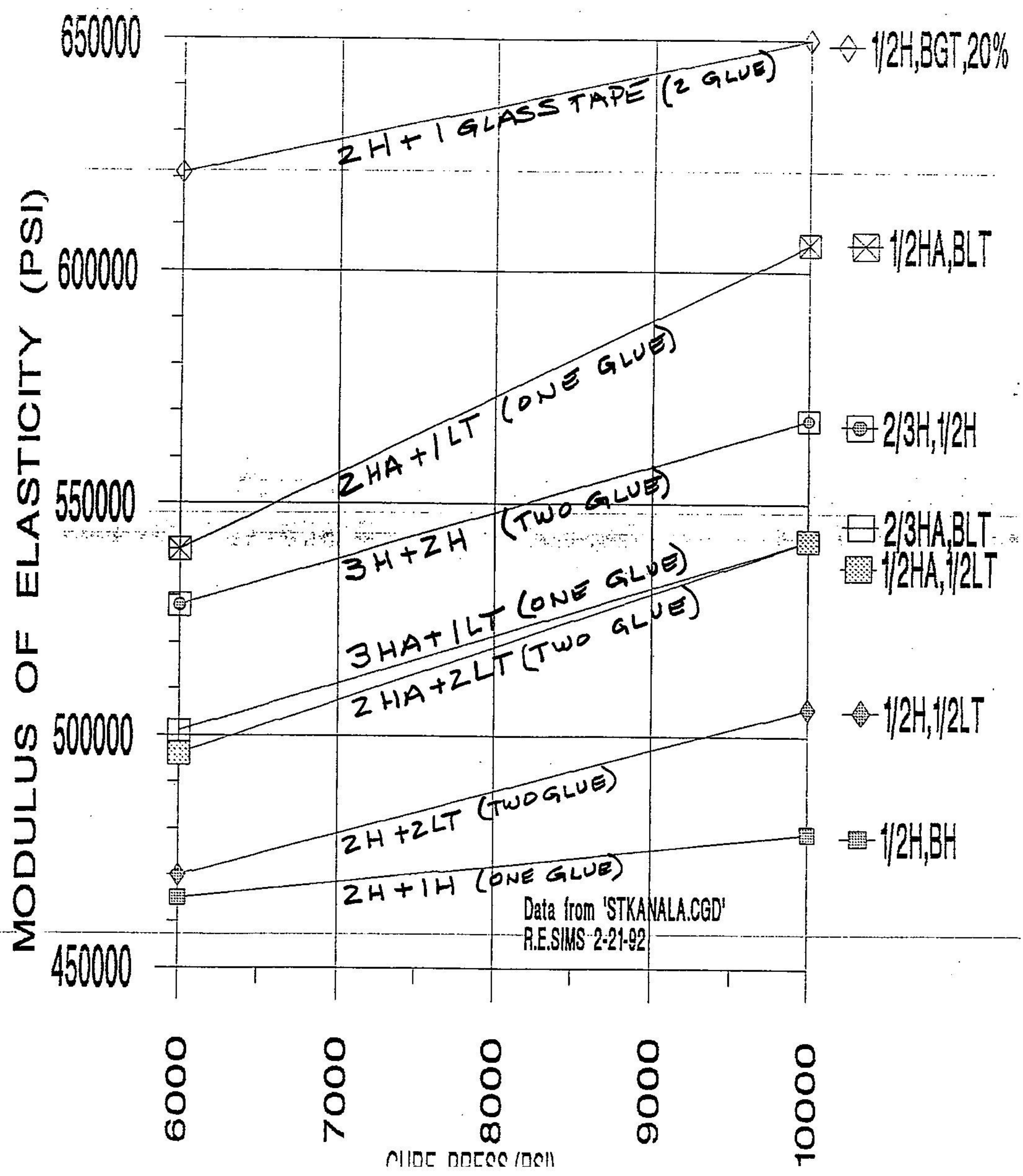

VARIOUS KAPTON H AND LT COMBINATIONS VS CREEP
(CHOICES CLOSE TO BASELINE)
HE3-1,2/3H+E,10K
HE2LTE-1,1/2H+E,BLT,10K
GT10,1/2H,BGT,20%,10K
BASELINE
POLY1,1/2CI,1/2RCI,10K
BNL TYPE
HL501,,1/2H,1/2LT,10K
OUTER COIL CHOICE
HL1,1/2H,BLT,10K
INNER COIL CHOICE
H3,1/2H,BH,10K
H1,2/3H,1/2H,10K
0.0000
0.0005
0.0010
0.0015
0.0020
COIL EQUIVALENT CREEP (INCHES)



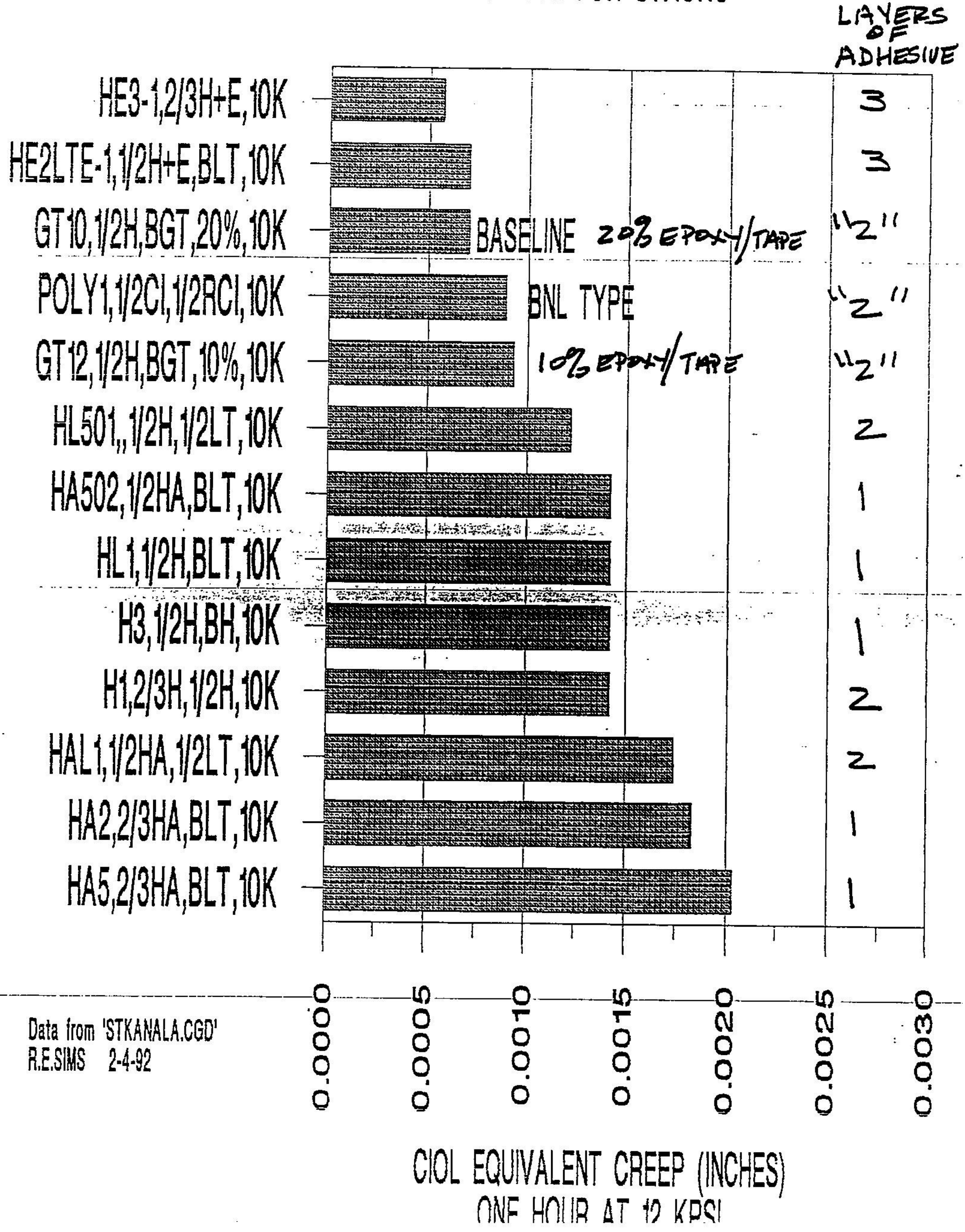
COISTCRP.CGG
R.E.SIMS 2-13-92


KAPTON CREEP VS CURE PRESSURE
TEN STACKS WERE CURED AT BOTH 6 KPSI AND
10 KPSI AT 275 F FOR 90 MINUTES
NOTE THAT LESS LAYERS MEANS LESS
SENSITIVITY TO MOLDING PRESSURE VARIATIONS
(WHICH ALSO MEANS LESS VARIATION WITH
MATERIAL TOLERANCES)
EQUIVALENT COIL CREEP (INCHES)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
3HA+1LT
3H+2H
2HA+2LT
2HA+1LT
2H+2LT
THREE LAYERS OF H
"THREE" LAYERS
HA5&6,2/3HA,BLT
HAL1&2,1/2HA,1/2LT
H1&2,2/3H,1/2H
HA502&3,1/2HA,BLT
H3&4,1/2H,BH
HL501&2,1/2H,1/2LT
GT10&11,1/2H,BGT,20%
6000
7000
8000
9000
10000
CURE PRESS.(PSI)
Data from 'STKANALA.CGD'
R.E.SIMS 2-13-92 KCRCPSI.CGG

MODULUS OF ELASTICITY VS CURING PRESSURE FOR KAPTON BRAND FILMS

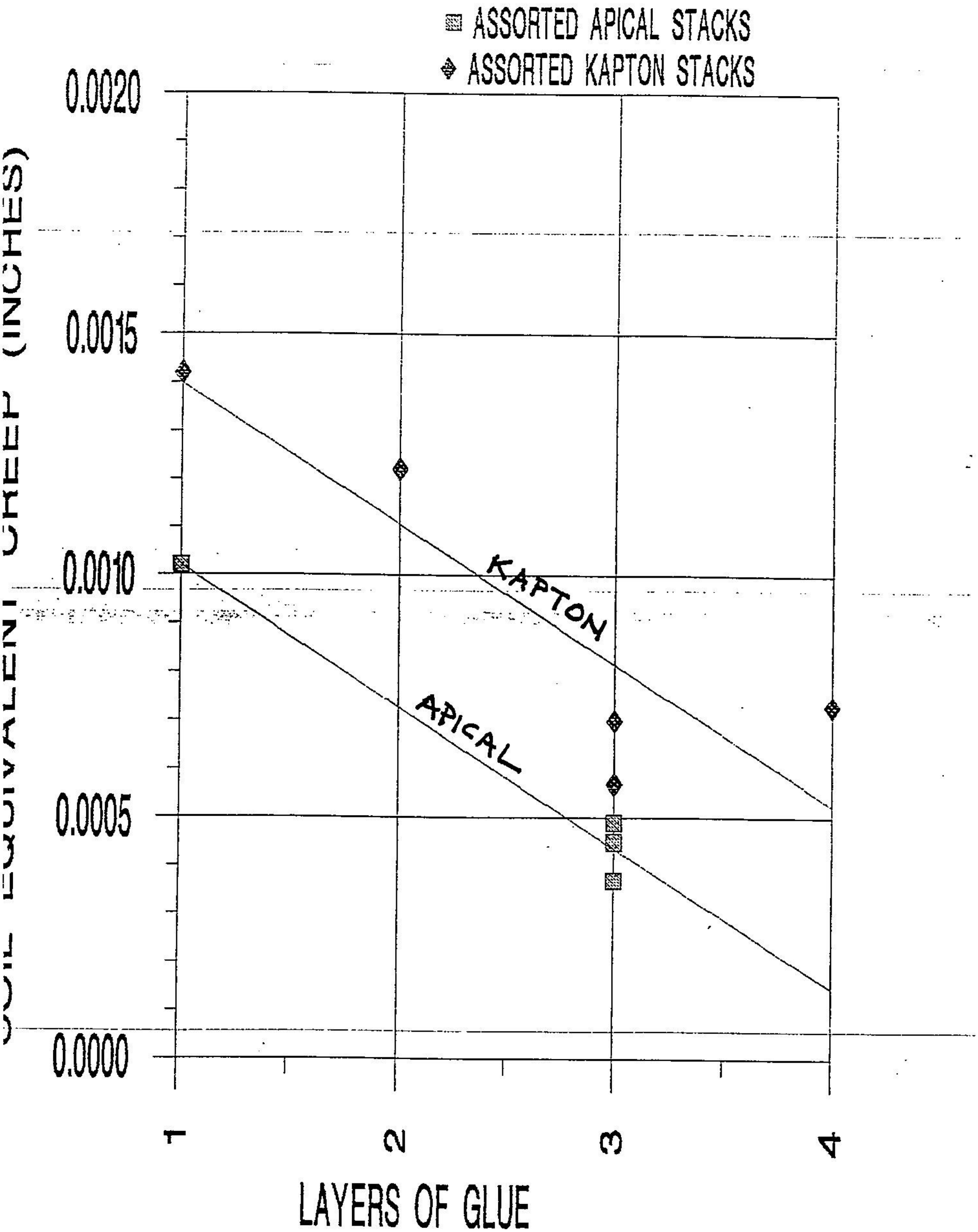


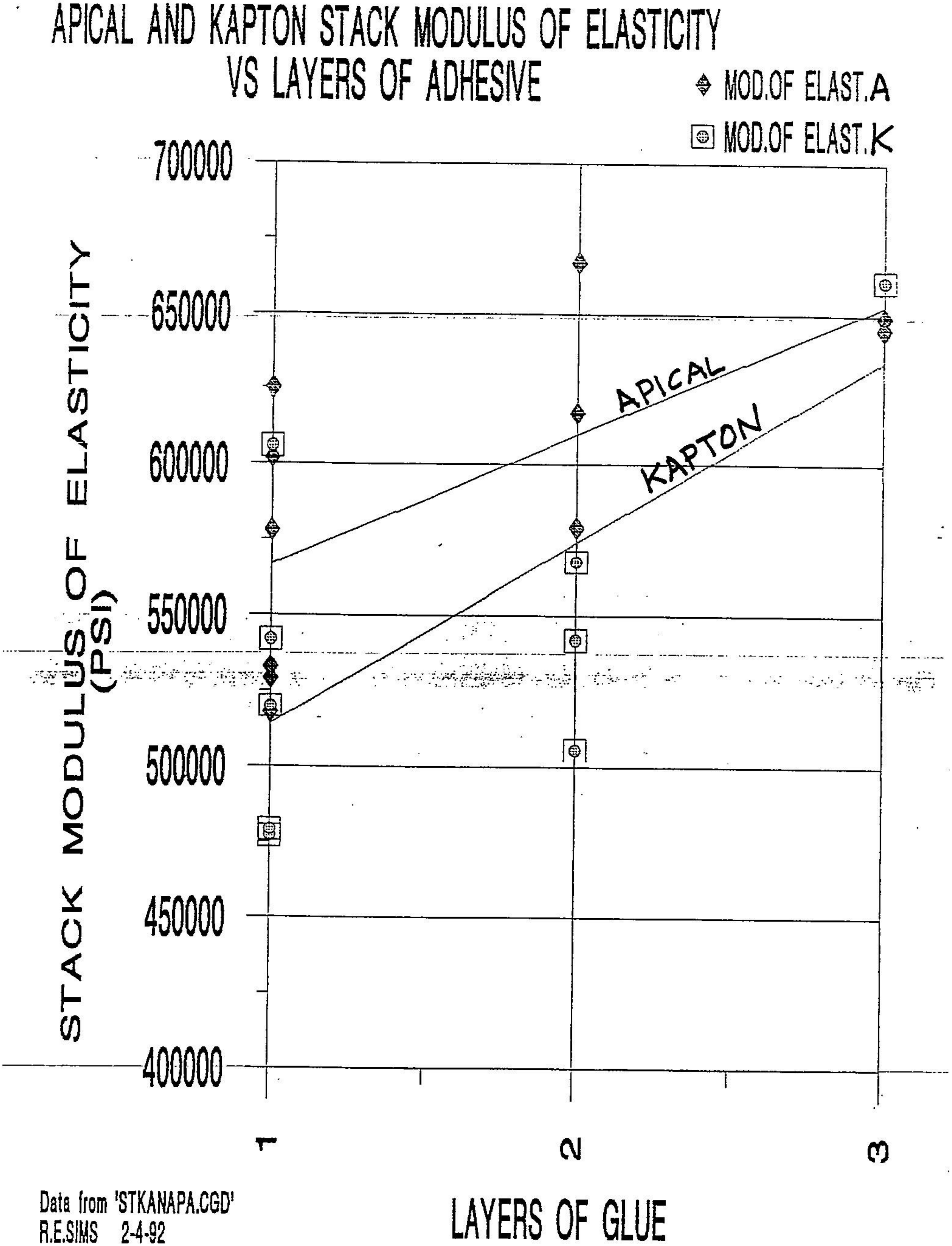
CREEP FOR SELECT KAPTON STACKS



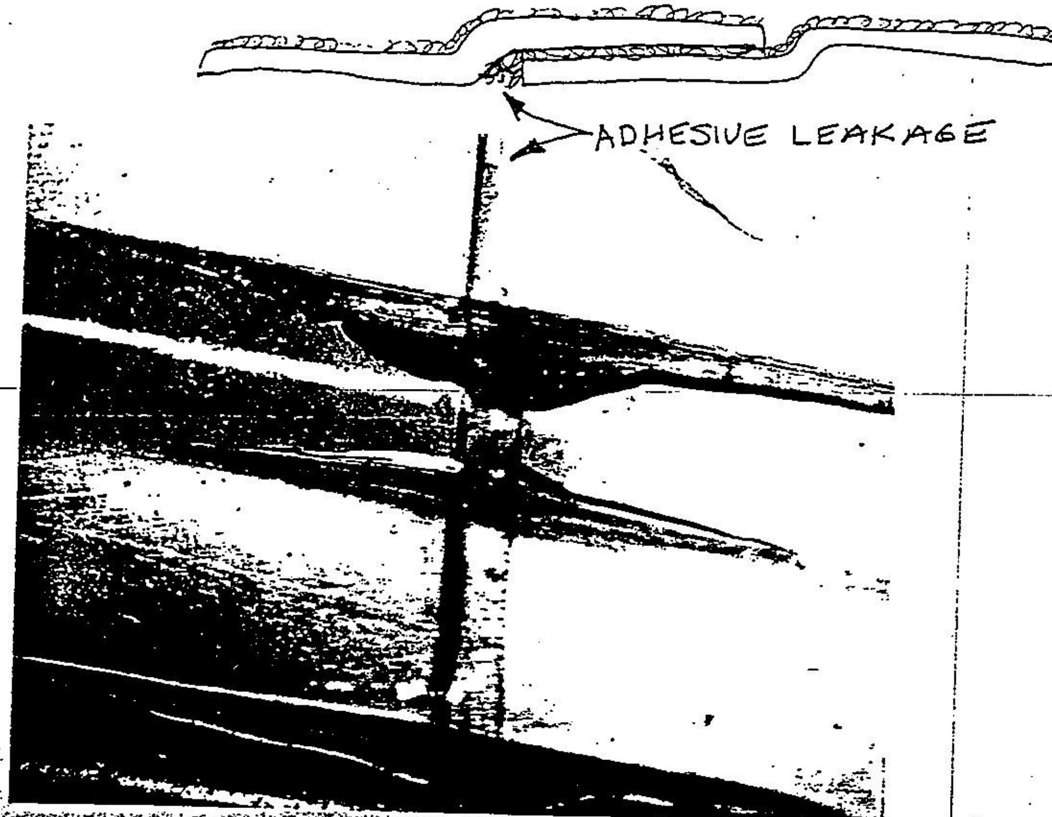
Data from 'STKANALA.CGD'
R.E.SIMS 2-4-92

EFFECT OF ADHESIVE LAYERS ON CREEP

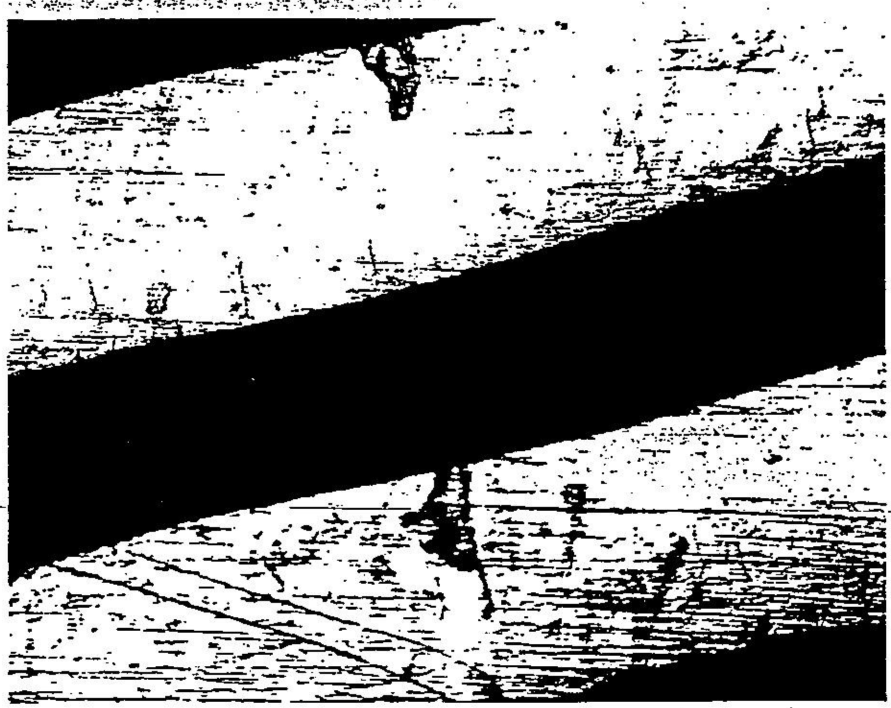




Data from 'STKANAPA.CGD'
R.E.SIMS 2-4-92



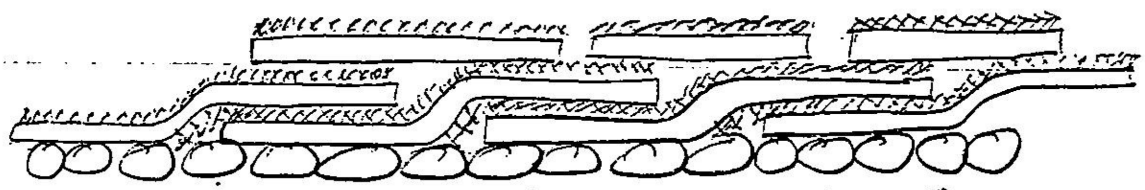
SEAM OF 50% OVERLAPPED APICAL TYPE NP WITH CRYORAD ADHESIVE ON TOP SIDE OF FILM. SOME CRYORAD ADHESIVE HAS FLOWED TO THE LOW PRESSURE AREAS.



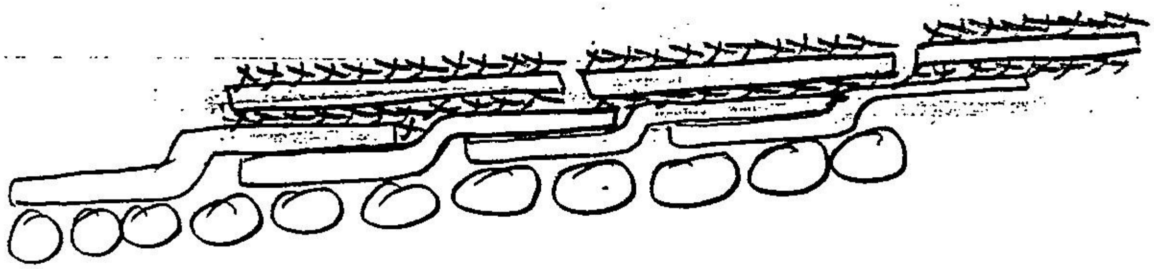
SMALL PATCHES OF CRYORAD HAVE "LEAKED" ON TO THE SURFACE OF THE STRANDS.

CRYORAD DROPLET BETWEEN STRANDS

R.E. SIMS 2-4-92



THREE LAYERS OF GLUE
(POSSIBLE GLUE LEAKAGE TO CABLE)



GLUE ON BOTH SIDES OF TOP LAYER
(NO APPARENT LEAKAGE OF GLUE TO CABLE)

BEST COMPROMISE?

Superconducting Super Collider Laboratory
Magnet Systems Division
2550 Beckleymeade Avenue, MS-1000
Dallas, TX 75237
Magnet Division Reception Tel: 214-708-2200
Magnet Division Director Fax: 214-708-0003
Plans & Programs Fax: 214-708-2127
Magnet Engineering Fax: 214-708-2059
Magnet Production Fax: 214-708-2351
Quality Assurance Fax: 214-708-2362
Test Group Fax:214-708-2363
Product Management Fax: 214-708-2265
MSD Systems Engineering Fax: 214-708-6316

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FROM: DICK SIMS

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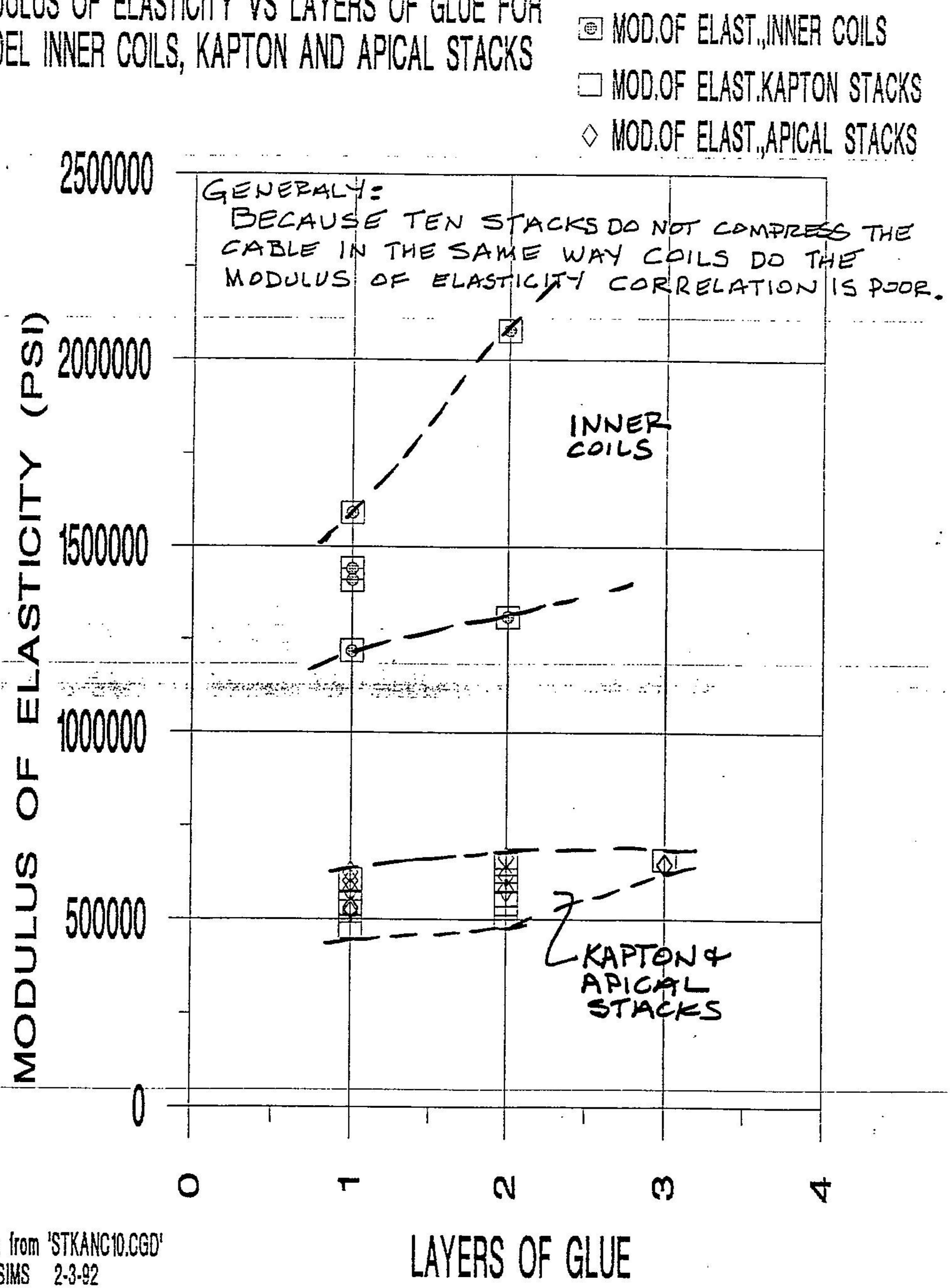
		TOTAL	0:22'45"	21	

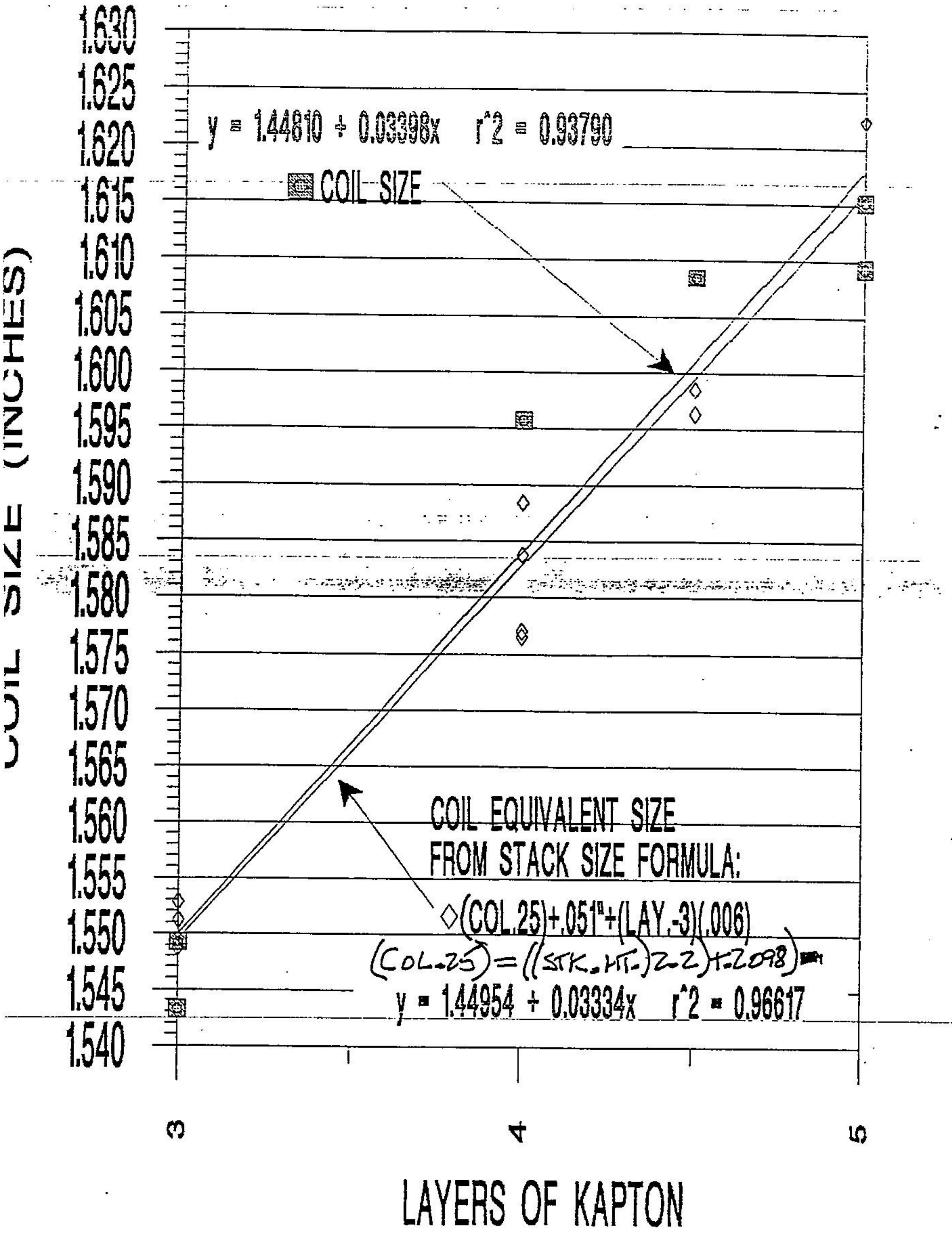
XEROX TELECOPIER 7021

MODULUS OF ELASTICITY VS LAYERS OF GLUE FOR MODEL INNER COILS, KAPTON AND APICAL STACKS



Data from 'STKANC10.CGD'
R.E.SIMS 2-3-92

PREDICTING COIL SIZE FROM STACK SIZE



CONCLUSIONS

Based on small quantities of ten stacks made from DuPont Kapton types H, HA, and LT. The epoxy used on the Kapton was 3M #2290

1. Removing the Glass-Epoxy tape increases stress relaxation as much as 2 to 3 times (unless under layers of polyimide utilize adhesive. See 5 below).

2. This stress relaxation can be minimized by:

   a. Use as few layers of Kapton as possible.
   b. Use high molding pressures (≥ 10 KPSI)
   c. Stay in the mold longer, preferably at the curing temperature
   d. A single ten stack made using DuPont CI and RCI at 225°C (438°F) showed a stress relaxation about 16% greater than Glass-epoxy, i.e., very close to glass epoxy.

3. The Glass-Tape system accommodates approximately twice the material tolerance variation that 3 layers of Kapton can. (.015" for glass tape, .007" for 3 layers of Kapton).

4. Single Kapton insulation systems <u>with no inner layer adhesive</u> have 10% to 25% lower final coil modulus of elasticity.

5. It appears that coils made <u>with inner</u> and <u>outer layer adhesives</u> would have creep levels <u>equal to or better than glass tape</u>.

6. It is difficult to extrapolate coil size from ten stack size with good accuracy. (Curved stacks would be better.)

7. Allied Signal Apical type NP film appears to provide lower creep than DuPont Kapton type K (by apprx. 22% to 50% depending on wraps and layers of adhesive).

8. Apical type NP film also appears to make ten stacks with slightly higher modulus of elasticity properties (by roughly 15%).

9. If "Loaded" films have lower cryogenic shrink and lower bulk modulus than non-loaded films, then DuPont "LT" film should be the "top" layer of insulation.

10. When adhesive is utilized on layers closest to cable, small amounts of adhesive can be found on the cable. (Could these small amounts of adhesive crack, exotherm, and cause a quench?)

11. A Spindel (SSCL) suggested utilizing adhesive on <u>both</u> sides of the top insulation layers, but not on the bottom layers. This should produce a good compromise which cannot leak adhesive onto the cable.

R. Bossert
Short Magnet Closeout
Oct. 27, 1992

Short Magnet Construction

Tasks performed by FNAL in fiscal 1992 on SSC short magnets consisted of:

¥ Short Magnet Construction and Testing

A series of five SSC short models were constructed with various cable insulation systems and tested. They were built for the purpose of analyzing cable insulation systems which did not include glass tape. In addition to the five magnets, three magnet sections were collared and sectioned for conductor placement analysis.

FY92 short models were also used to test alternate materials for the coil end parts.

¥ Iteration #2 End Part Design, Construction and Analysis

The configuration of the paths which define the positions of the end parts were redesigned with the goal of more accurately supporting the conductors in the end area. The new design was called "iteration #2". Parts were designed and wound into coils. These coils were potted, sectioned and analyzed.

FY92 Short Dipole Characteristics

¥ Cable insulation which does not include glass tape.

- Some Kapton with Scotch 2290 adhesive
- Some Apical with Cryorad adhesive

¥ Modified cross section with shimmed wedges to compensate for the azimuthally thinner cable insulation.

¥ Iteration #1 end part design (same as ASST).

¥ Some magnets had one piece end keys on inner coils.

¥ Some alternate material end parts.

¥ Slightly modified coil insulation system (one layer of .003 inch thick kapton added between inner and outer coils to compensate for the radially thinner cable insulation.)

¥ Alternate design strip heaters.

- Made by two different vendors
- Some with 1 element, some with 3 elements.
- Experiments with different placement of strip heaters.
- Experiments with different element thicknesses

Specific Magnet Features

	Cable Insulation		End Parts	Coil Insulation	Strip Heaters
Magnet No.	Inner Coil	Outer Coil			
DSI 340	3H+2H 2290 one side	3H+2H 2290 one side	N/A	Standard	None
DSI341	2H+Butt LT one side 2290	2H+2LT 2290 one side	N/A	Standard	None
DSI342	2NP+ButtNP Cr both sides	2NP+2NP Cr both sides	N/A	Standard	None
DSA330	2H+ButtLT one side 2290	2H+2LT 2290 one side	G-10	Standard	None
DSA331	3NP Cr one side	2NP Cr one side + 2NP Cr one side	G-10/Sp. RTM	Standard	None
DSA332	2H+ButtLT one side 2290	2H+2LT 2290 one side	G-10	Standard	2 Lars single element 2 Sheldahl single element
DSA333	2H+ButtLT 2290 both sides	2H+2LT 2290 both sides	G-10/Torlon	Only 1 layer of kapton between strip heater and outer coil.	2 Sheldahl single element 2 Sheldahl triple element
DSA334	2NP+ButtNP Cr both sides	2NP+2NP Cr both sides	G-10/Cryorad	Only 1 layer of kapton between strip heater and outer coil.	All Sheldahl single element 2 standard .001 thick 2 .0005 thick

Coil Sizes and Shims

	Coil Sizes				Coil Shims		Total Coil Package size	
Magnet No.	Upper Inner	Lower Inner	Upper Outer	Lower Outer	Inner	Outer	Inner	Outer
DSA330	12	11	-5.8	-8.6	0	5	11.5	-0.75
DSA331	9.8	10.9	-3.8	-1.5	0,5*	0	17.75	-2.65
DSA332	12.4	10.9	-11.9	-11	0	10	1.65	1.45
DSA333	7.2	6.6	-5.3	-6	2	4	8.9	-1.65
DSA334	11.7	11	-5.8	-4.5	0	4	11.35	-1.15

*The lower inner coil in this magnet was built with a wedge which was .005 smaller than the design size. This coil had a shim of 5 mils while the upper shim was 0.

All values in thousanths of inches

Goal was .009 larger than the master for inner coils and .001 smaller than the master for outer coils.

Assembly Procedure

1.) Preform coils.

2.) Wind coils with 85 lbs tension. This is more than was used for long coils but the same as the glass tape short coils.

3.) Cure coils. Curing cycle was the same as with glass tape coils for the kapton with 2290 adhesive. Cryorad adhesive requires a slightly higher temperature

4.) Measure coils azimuthally, radially and longitudinally.

5.) Assemble coils, insulate and add strip heaters.

6.) Add collars and strain gage packs.

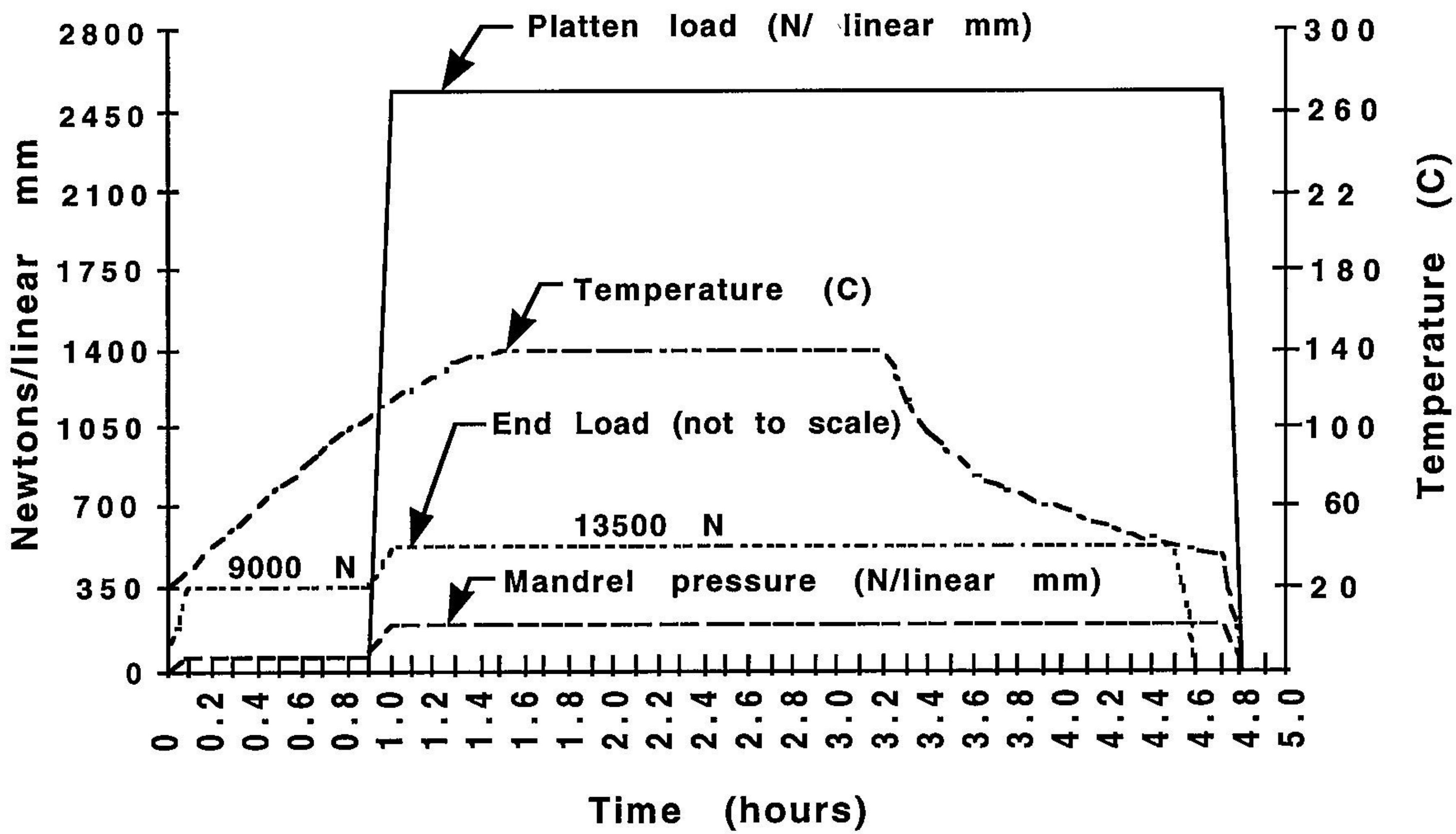
7.) Press and key coils. Procedure same as ASST style magnets.

8.) Install end clamps.

9.) Yoke magnets.

10.) Add end plates and bullet (end force) gages.

11.) Final electrical checks.



Platten load (N/ linear mm)
Temperature (C)
End Load (not to scale)
13500 N
9000 N
Mandrel pressure (N/linear mm)
Newtons/linear mm
2800
2450
2100
1750
1400
1050
700
350
0
Temperature (C)
300
260
22
180
140
100
60
20
Time (hours)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0

Coil Stresses during Assembly

	Peak Stresses during Keying		Stresses After Keying		Stresses after Yoking		Total Coil Package size	
Magnet No.	Inner coils	Outer Coils	Inner coils	Outer Coils	Inner coils	Outer Coils	Inner coils	Outer Coils
DSA330	15.5	17.7	7.1	9.3	8.4	9.3	11.5	-0.75
DSA331	18.5	10.5	10.1	5.1	11.4	5.1	17.75	-2.65
DSA332	16.5	17.8	8.3	11	9.7	10.7	1.65	-1.45
DSA333/1	19.6	14.1	13.8	7.2	12.3	6.7		
DSA333/2	18.3	15.2	10.1	6.7	11.4	7.2	8.9	-1.65
DSA334	18.2	17.1	10.9	10.8	11.6	10.7	11.35	-1.15

All values in ksi.

Design goals were 8-12 ksi for inner coil and 6-10 ksi for outer coil.

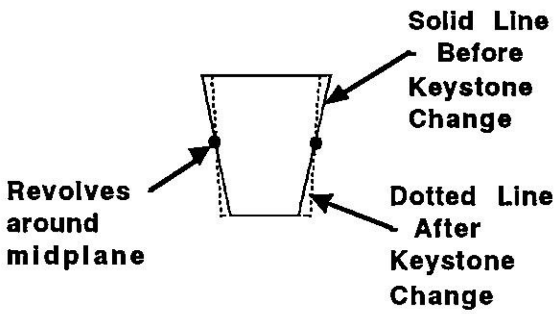
Alternate End Part Materials in FY92 Short Models   TS-SSC 92-083 R. Bossert 10-6-92

Below is a list of all coils from FY92 which contained end parts other than the "baseline" machined G-10:

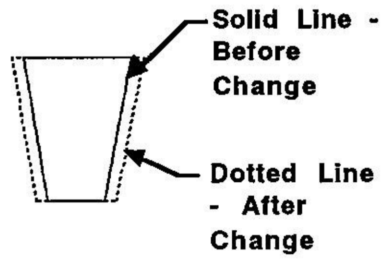
Coil No.	Magnet No.	Date comp.	Material Used	Notes	Cable Insulation Used
1M-50-126 Inner Coil	None	8/16/91	Stycast on Return End Coated Aluminum lead end key (polyphenylene sulfide)	Stycast only on key, spacer #3 and saddle. Other parts filled in with G-10. Coil was not sectioned	1/2 lap H film Butt lap glass tape
1M-50-127 Inner Coil	None	9/6/91	Spaulding RTM (102) on return end Coated Aluminum on lead end key (epoxy ester)	Spaulding RTM only on key and saddle. Other parts filled in with G-10. Coil was not sectioned	1/2 lap H film Butt lap glass tape
SSCL outer coil. No FNAL number.	None	9/10/91	RTM "Cryorad" on Return end Saddle. Outer Coil.	RTM part only on return end saddle. Other parts will be filled in with G-10. Coil was sectioned and delivered to F. Nobrega.	Cryorad adhesive Insulation ?
1M-50-128 Inner coil	None	9/20/91	Spaulding RTM (101) on return end Coated Aluminum on lead end key. (Dupont polyimide varnish)	Spaulding RTM only on key and saddle. Other parts filled in with G-10. Coil was not sectioned.	1/2 lap H film Butt lap glass tape
1M-50-129 Inner coil	None	10/1/91	Amoco Torlon machined by VMS on return end. Coated Alum. on lead end key.	All return end parts are Torlon Coil was potted and sectioned.	1/2 lap H film 1/2 lap H film w/adh (2290) on one side.
1M-50-130 Inner coil	DSI340	10/15/91	Green Tweed Arlon (PEEK) machined by VMS on return end. Coated aluminim on lead end key	All return end parts are Arlon. Coil was potted and sectioned.	2/3 lap H film 1/2 lap H film w/adh (2290) on one side.
1M-50-131 Inner coil	DSI340	11/12/91	Machined G-10 on all parts except coated aluminum keys on both ends.		2/3 lap H film 1/2 lap H film w/adh (2290) on one side.
1M-50-135 Inner coil	DSA330	1/20/92	Spaulding RTM (101) on return end	Spaulding RTM only on key and saddle. Other parts filled in with G-10.	1/2 lap H film Butt lap LT film w/ adh (2290) on one side.
1M-50-136 Inner coil	DSA330	1/23/92	Spaulding RTM (101) on return end	Spaulding RTM only on key and saddle. Other parts filled in with G-10.	1/2 lap H film Butt lap LT film w/ adh (2290) on one side.
1M-50-143 Inner coil	DSA333	9/10/92	Amoco Torlon machined by VMS on return end.	Magnet cold tested at FNAL.	1/2 lap H film Butt lap LT film w/ adh (2290) on both sides
1M-50-144 Inner coil	DSA333	9/15/92	Amoco Torlon machined by VMS on return end.	Magnet cold tested at FNAL.	1/2 lap H film Butt lap LT film w/ adh (2290) on both sides
1M-50-147 Inner coil	DSA334	8/15/92	RTM "Cryorad" on return end key and saddle.	Magnet cold tested at FNAL. Parts supplied by F. Nobrega. Other parts filled in with G-10.	1/2 lap Apical NP film Butt lap NP film w/ adh (Cryorad) on both sides
1M-50-246 Outer coil	DSA334	8/20/92	RTM "Cryorad" on return end key and saddle.	Magnet cold tested at FNAL. Parts supplied by F. Nobrega. Other parts filled in with G-10.	1/2 lap Apical NP film Butt lap NP film w/ adh (Cryorad) on both sides

Iteration #2 End Part Design

Program BEND accepts input to locally change the cable shape. Both keystone and midplane thickness can be altered independently as shown. The changes are input based on empirical data.



Keystone Change



Midplane Thickness Change

Original end designs on 40mm SSC dipoles were done using the nominal shape of the cable as compressed in the straight section. Changes in end parts for 50mm coils were made based on observations of sectioned 40mm ends. A second iteration of the 50mm was made with changes based on observations of the original 50mm ends. The keystone angle was made smaller (dekeystoning) and the conductor midthickness was increased. Percentages are shown for both the iteration #1 and #2 designs. Iteration #1 was used for the ASST dipoles. Iteration #2 was used in one "off line" coil in FY92.

	Iteration #1 Inner	Iteration #1 Outer	Iteration #2 Inner	Iteration #2 Outer
% Dekeystoned, Mid-group	40%	40%	90%	90%
% Dekeystoned, At Nose	30%	30%	80%	80%
% Midthickness Increase, Mid-group	2.7%	2.7%	6.4%	5.9%
% Midthickness Increase, At Nose	0%	0%	7.4%	5.1%

Conclusions

¥ Coil winding and curing of "kapton only" coils can be done in the same manner as the glass tape coils if the curing mold shim is adjusted appropriately.

¥ Cryorad adhesive, if cured at 140C (10C below the recommended temperature), does not bond as well as 2290, but bonds well enough to make an acceptable coil.

¥ Several End part materials (Torlon, PEEK, Spaulding RTM, Cryorad, coated aluminum) have passed the curing cycle without damage.

¥ Short magnets have performed adequately with Spaulding RTM and Cryorad end parts.

¥ All quenches in the magnet with Torlon end parts were in the region of the parts, but the reason is unknown.

¥ Iteration #2 end part design has not yet been proven to be superior to Iteration #1, although more study needs to be done.

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MECHANICAL BEHAVIOR OF "POST-ASST" DESIGN 5 CM MODEL DIPOLE

Tariq S. Jaffery
Fermi National Accelerator Laboratory
Review of Short Model Dipole Test Results.
October 27, 1992

PRESTRESS CHANGE WITH COOLDOWN
1.5 m Long , 50 mm Aperture
SSC Model Dipoles Tested 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
DSA326 (TC1)	-34	-25	4.8
DSA326 (TC2)	-37	-23	5
DSA326 (TC3)	-36	-22	-2.5
DSA101 (TC1)	-35	-22	---
DSA102 (TC1)	-49	-18	---
DSA328 (TC1)	-36	-8.5	6.6
DSA329 (TC1)	-34	-16	1.4
DSA329 (TC2)	-35	-17	1.1

PRESTRESS CHANGE WITH COOLDOWN
1.5 m Long , 5 cm Aperture
SSC Model Dipoles Built &Tested at Fermilab
"POST-ASST" Design

Magnet	Coil Stress Change (MPa) Inner Coil		Outer Coil		End Force Change (kN)	
	w c		w c		w c	
DSA329 (TC1)	-34	(67.4-33)	(37.8-22)	-16	(4.3;5.7)	+1.4
DSA329 (TC2)	-35	(67.4-33)	(37.8-22)	-17	(5.6;6.5)	+1.1
DSA329B (TC1)	-33	(66.4-33)	(39-17)	- 22	(4.9;6.3)	+1.4
DSA330 (TC1)	-28	(56.4-28.2)	(63.3-46.8)	-17	(4.4;3.0)	-1.4
DSA331 (TC1)	-36	(80.6-44.7)	(34.9-22)	-13	(5.1;6.4)	+1.4
DSA331 (TC2)	-39	(82.2-33)	(30.5-20.8)	-10	(6;6.9)	+1.0
DSA332 (TC1)	-27	(60-33)	(73.0-65.0)	- 8	(4.3;5.9)	+1.6
DSA333 (TC1)	-13	(76-62.7)	(49.4-25.6)	-24	(6;6.9)	+1.0
DSA334 (TC1)	-39	(78.8-40)	(74-52)	-22	(5.2;6.1)	+0.9
DSA323B (TC1)	-39	(77-38)	(38.0-29.0)	-9	(4.1;8.4)	+4.3

TABLE I. Salient Features of Post-ASST Model Collider Dipoles Built by Fermilab

Magnet	Special Features	Pole Shim (mm) Inner/Outer	Coil Insulation
323	square key	0 / 0	Kapton H film + epoxy impregnated glass tape
323B	intermediate key	+0.13 / -0.13 (5 mil)	
329	1-Piece keys		Kapton H film + epoxy impregnated glass tape and Kapton only on all wedges
329B	2-Piece keys in RE	+0.09 / 0 (3.5 mil)	
330	molded keys and saddles[1]	0 / +0.25 (2x5 mil)	All magnets: Kapton with scotch 2290; cures at 135^0 C
332	G-10CR same as ASST	0 / +0.51 (2x10 mil)	In coil=2H+buttLT one side; out coil = 2H+2LT one side
333	molded keys and saddles[2]	+0.10/ +0.2	DSA333 all same except In coils=2H+buttLT both side
331	G-10CR end part	+0.13 / 0	Apical film with Cryorad adhesive; cures at 140-155^0 C In coil=3NP+buttLT one side; out coil = 2H+2LT one side
334	molded keys and saddles[3]	0 / +0.20	In coil=2NP+buttNP both side Out coil = 2NP+2NP 1-side

1 = Spalding part; 2 = Torlon part; 3 = Cryorad part

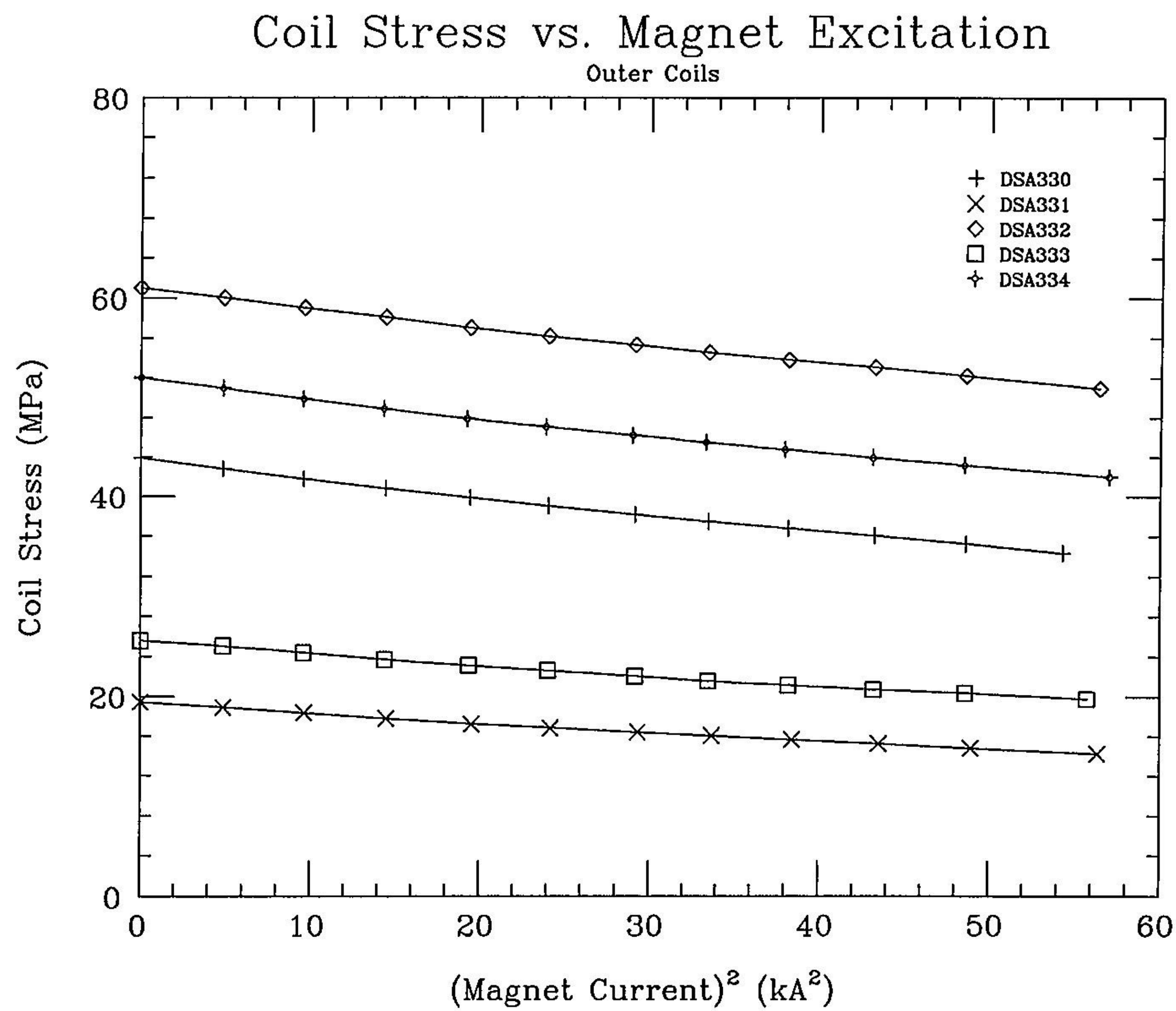
Quench current (Iq] as a function of temperature. The temperature dependence of quench current for these magnets is about 18%/K. Data is not corrected for temperature dependence since temperature variation from quench to quench is within 20-40mK. Lab2 cryogenic temperature monitoring system is good to within 10 mK[8]. The measured difference in plateau quench current (ΔIq) is well above the predicted ΔIq based on short sample magnet performance, in the normal temperature range $\geq$ 3.8K. This shows that the magnets have reached the conductor limited quench. DSA329 and DSA329B were quenched at 3.0K as well. The highest quench current on DSA329 at 3.0K was 8926 at 25 A/s and it was still training when testing was stopped.

The change in pressure, with excitation, of outer coils of some magnets (e.g. DSA331) is very small as compared to their respective inner coils. This behavior in outer coils can be due to lack of contact between the collar and the yoke in the vertical direction[4]. Pressure changes in inner coils during excitation are correlated to their initial prestresses. As it can be seen in Fig.1 that magnets with higher initial prestress tend to loose more pressure during excitation.The force measured, by the bullet gages, between the coil end clamp and the end plate, shown in Fig. 2, increases in proportion to current squared. The longitudinal force in the end increases by about 20 kN when the magnet is at 7.5 kA, while the total end force is estimated[5] at 3 kN / $(kA)^2$. This is a small fraction of the total electro-magnetic force in the coil, as most of the axial force is transferred to the shell through friction between coil and the support structure. Bullet gage preloads changed over thermal cycle in DSA329, 331 and 332, but it does not seem to change the magnet's quench performance.

DSA323 was unkeyed and reassembled as DSA323B with similar pole shims, aluminum end can and collar keying (table I) as DSA324. Since the cable used to wind the DSA323 and 324 coils were from the same reel, one would expect DSA323B to behave in a similar fashion as DSA324. Previously DSA323 quenched on the down ramp after exceeding 7 kA many times without quenching[3]. For DSA323B the average prestress on inner coils was doubled and it was lowered for the outer coils. DSA323B was successfully cold tested without any down ramp quenches. The exact cause of down ramp quenching is not clear. It could be related to either the stainless steel end clamp or lower prestress in the inner coils.

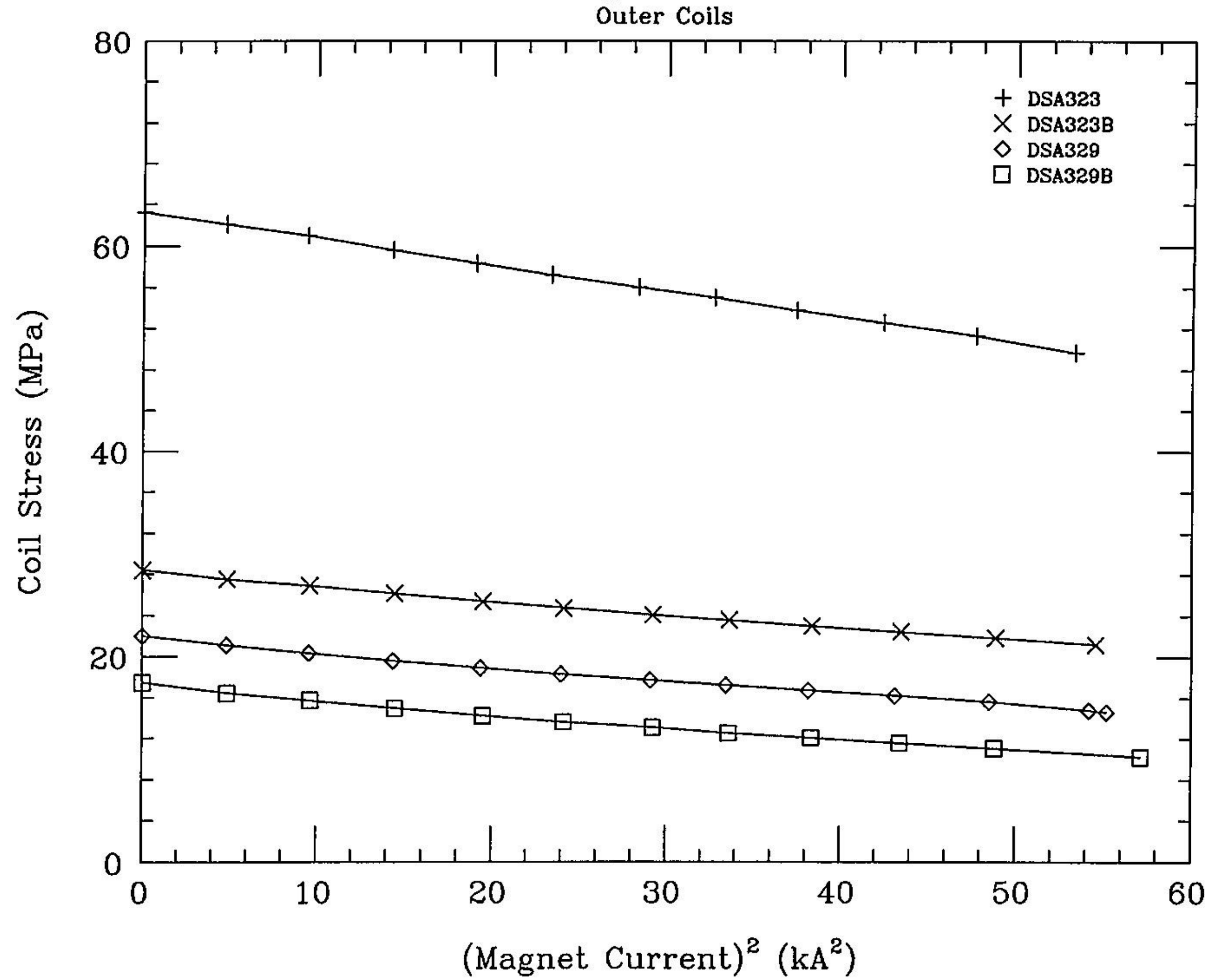
Design Change in DSA329 (2-piece Pole End Key)

The first quench in DSA329B (6438 A) is located near the return end voltage tap, very close to the collet end clamp and the collared part of the coil, near the pole end key. Most likely this is due to a design change, in which the pole end key which used to be a single piece, was made into a 2-piece key. Since it can not be ensured that the end key is seated properly during assembly, we suggest that the quench occurs as the key moves into a stable position. Similar behavior was observed in Fermilab built long magnets with 2-piece key. A 2-piece key might aid in assembly but it seems to degrade the magnet's performance.



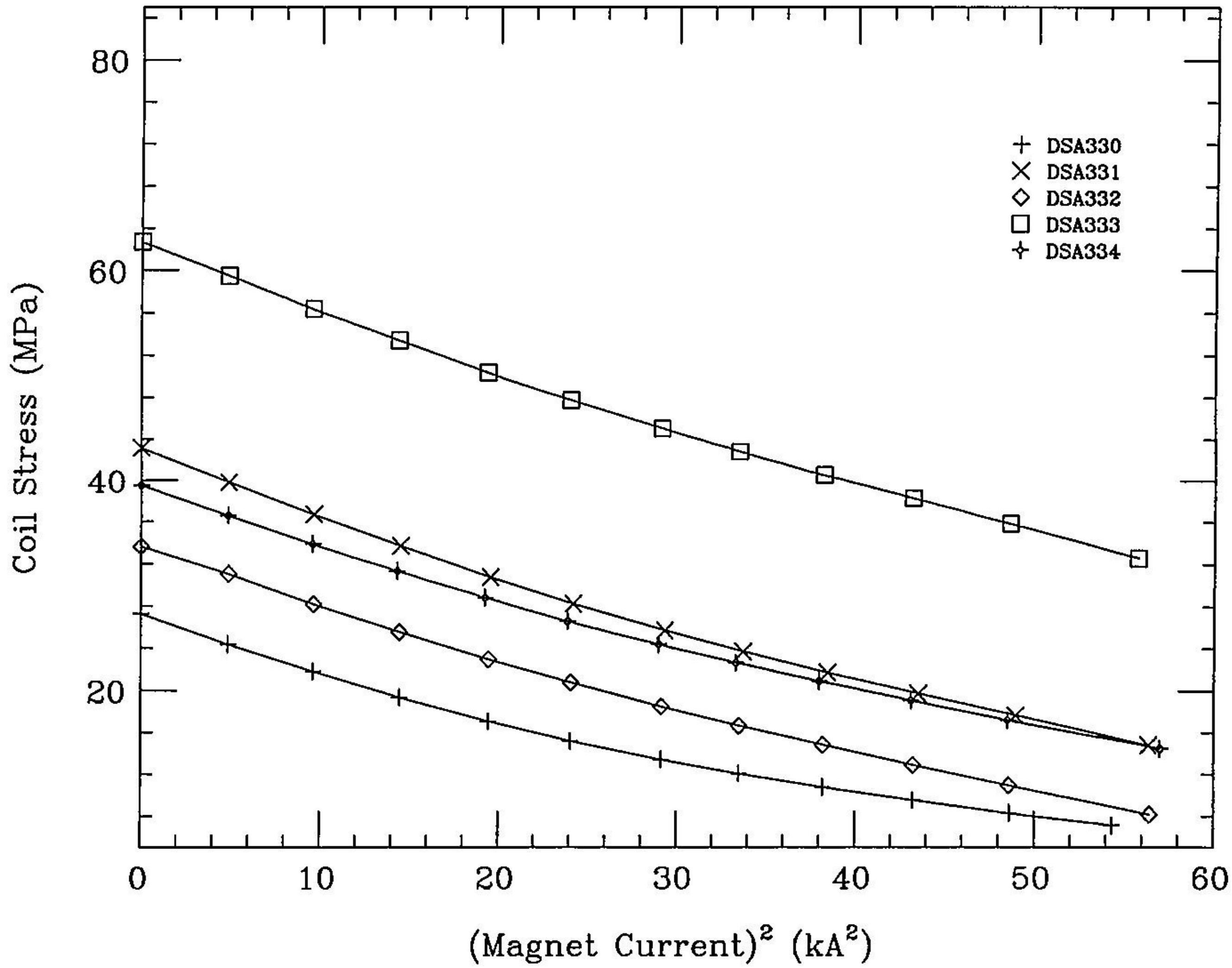
Coil Stress vs. Magnet Excitation
Outer Coils
80
60
40
20
0
0
10
20
30
40
50
60
Coil Stress (MPa)
(Magnet Current)^2 (kA^2)
DSA330
DSA331
DSA332
DSA333
DSA334

Coil Stress vs. Magnet Excitation

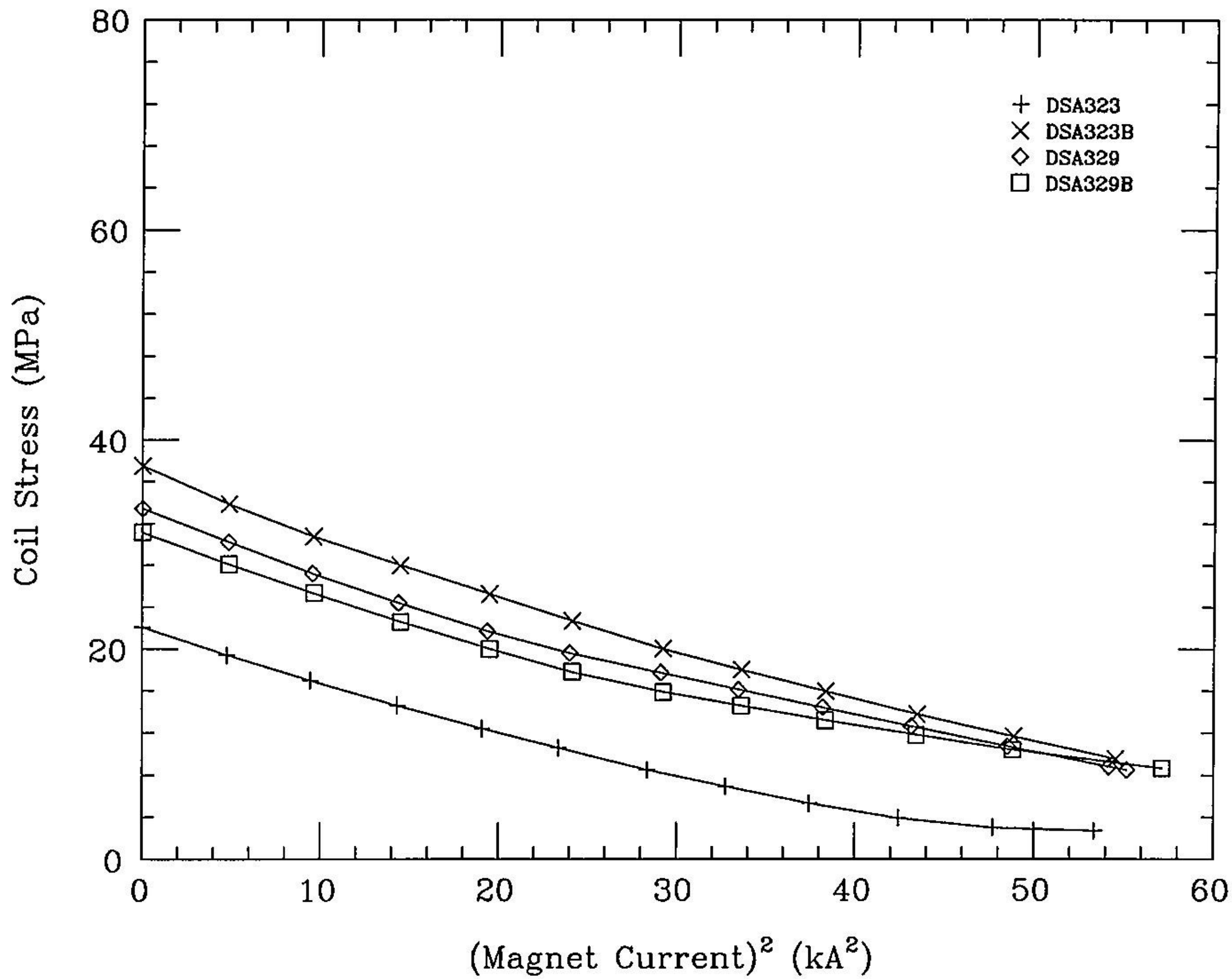


Coil Stress vs. Magnet Excitation

Inner Coils

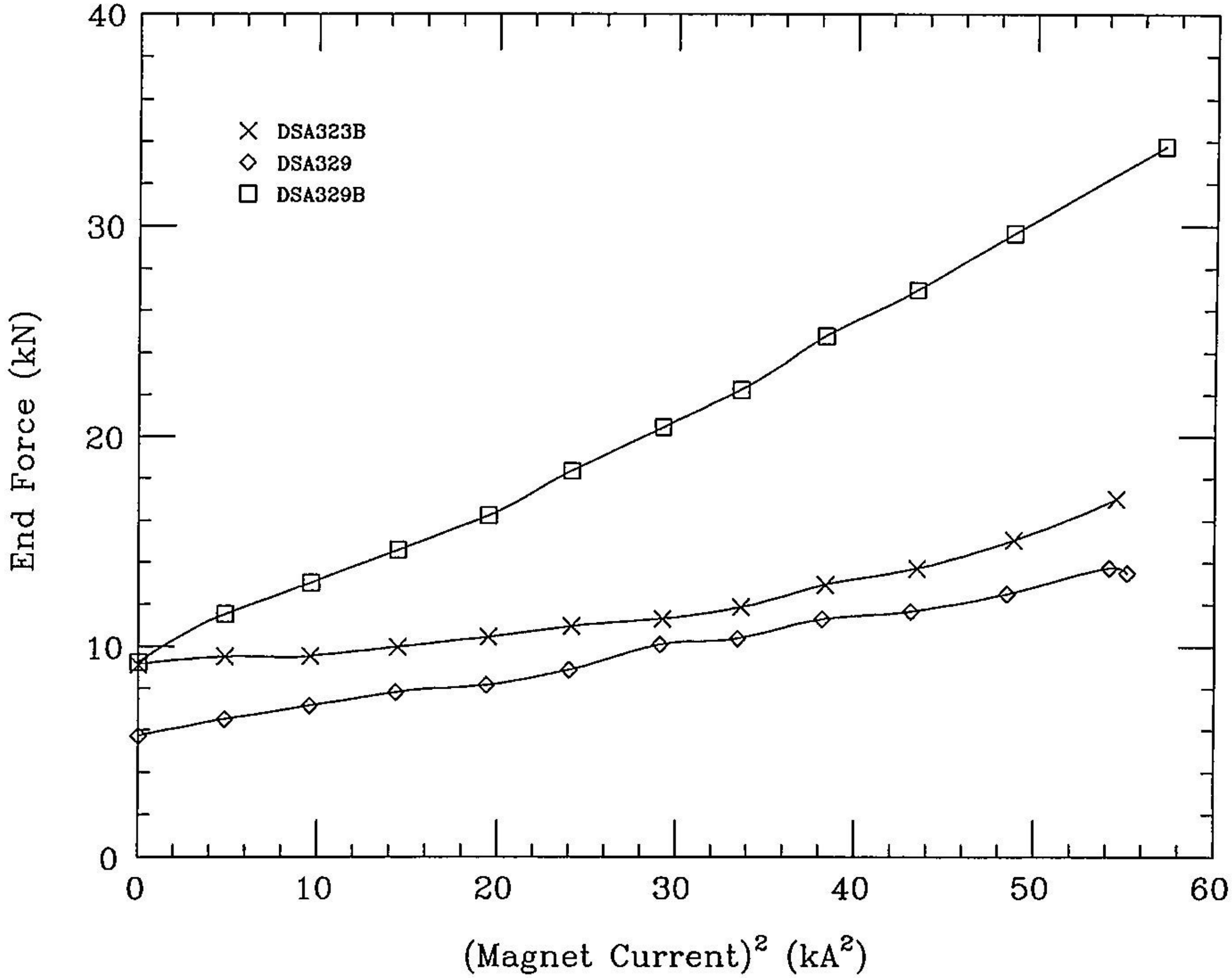


INNER COLLAR GAGES



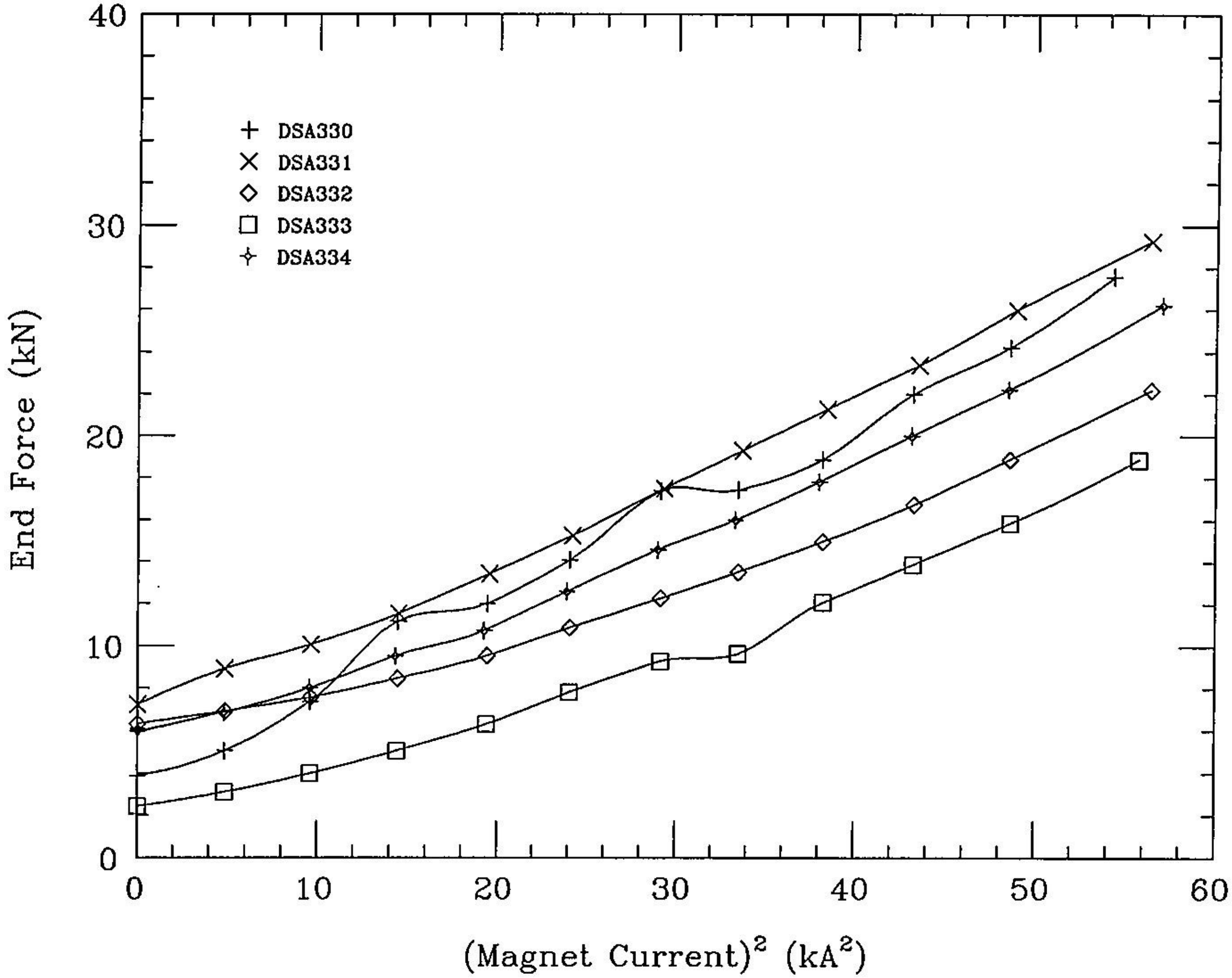
IO4LLETS-4,K-1

END FORCE vs. MAGNET EXCITATION



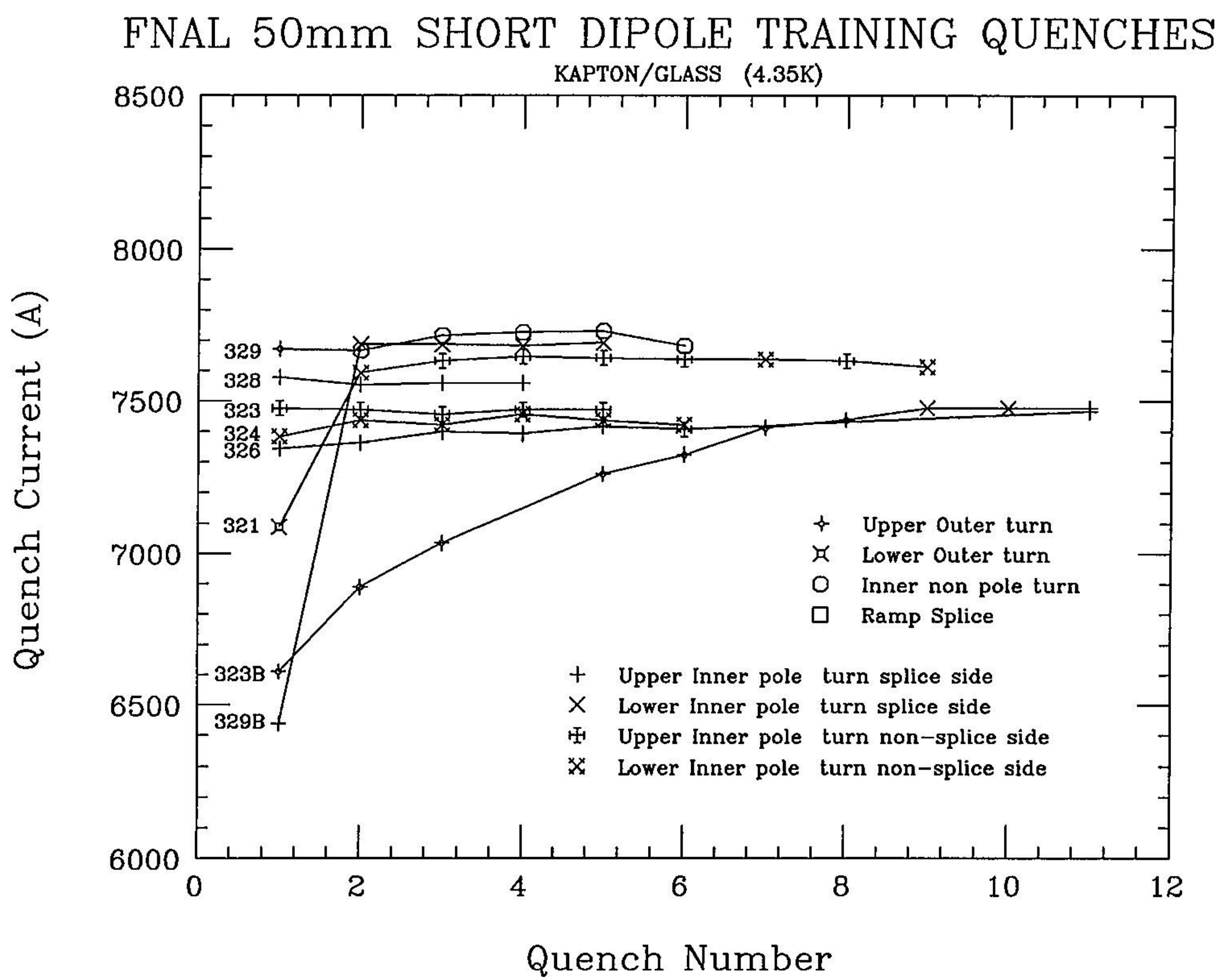
BULLETS . K-2

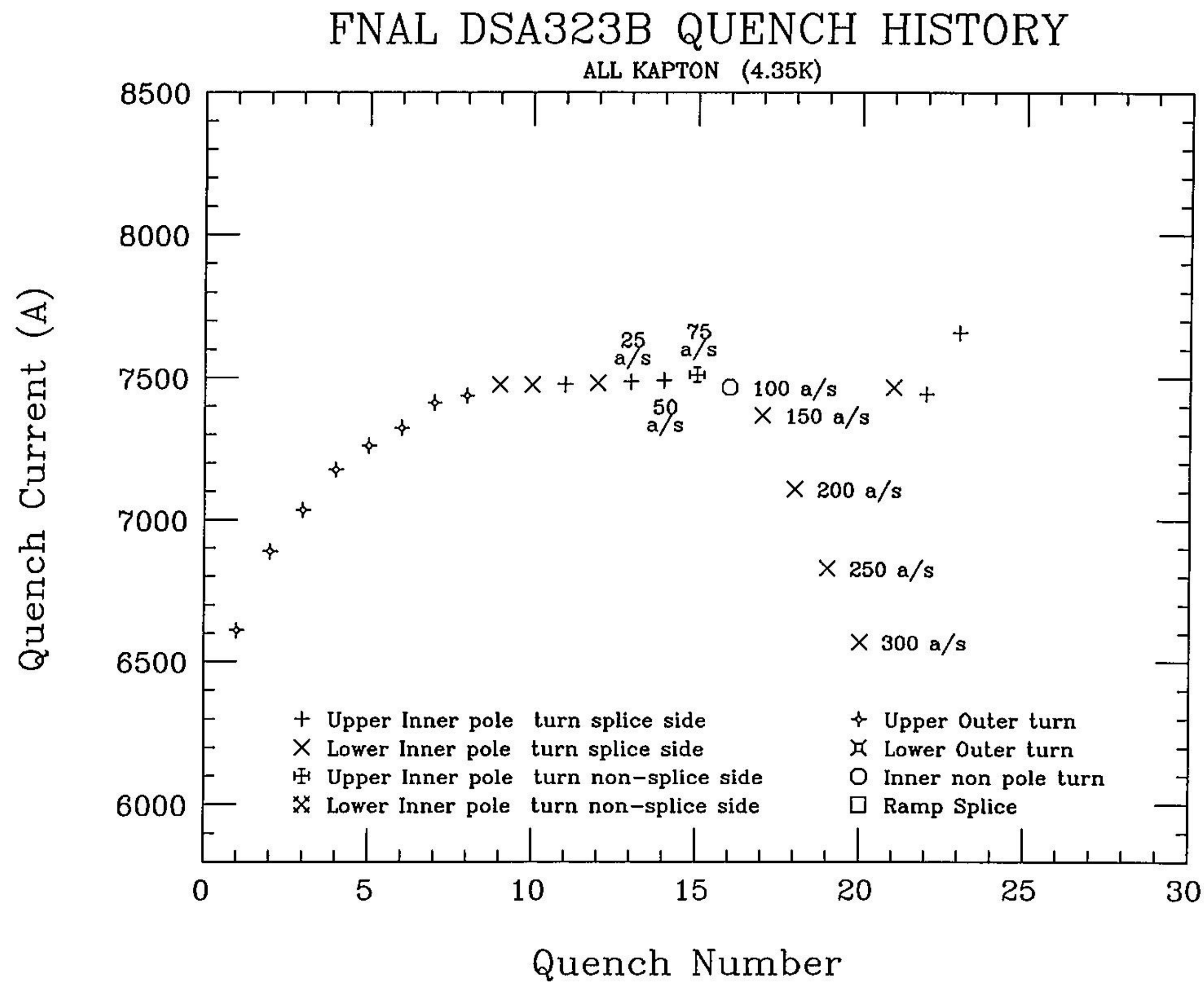
END FORCE vs. MAGNET EXCITATION



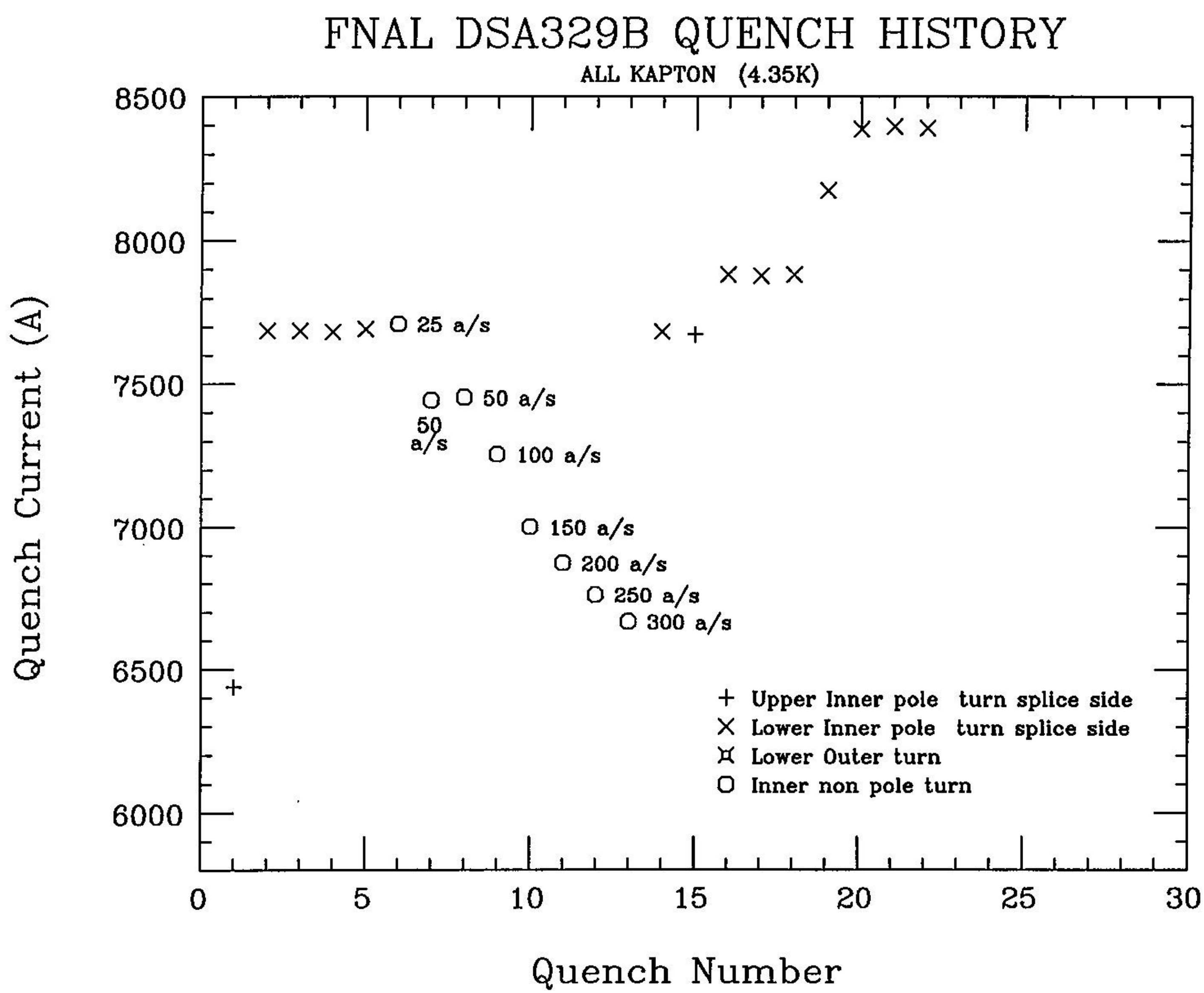
QUENCH PERFORMANCE OF "POST-ASST" DESIGN 5 CM MODEL DIPOLE

Tariq S. Jaffery
Fermi National Accelerator Laboratory
Review of Short Model Dipole Test Results
October 27, 1992

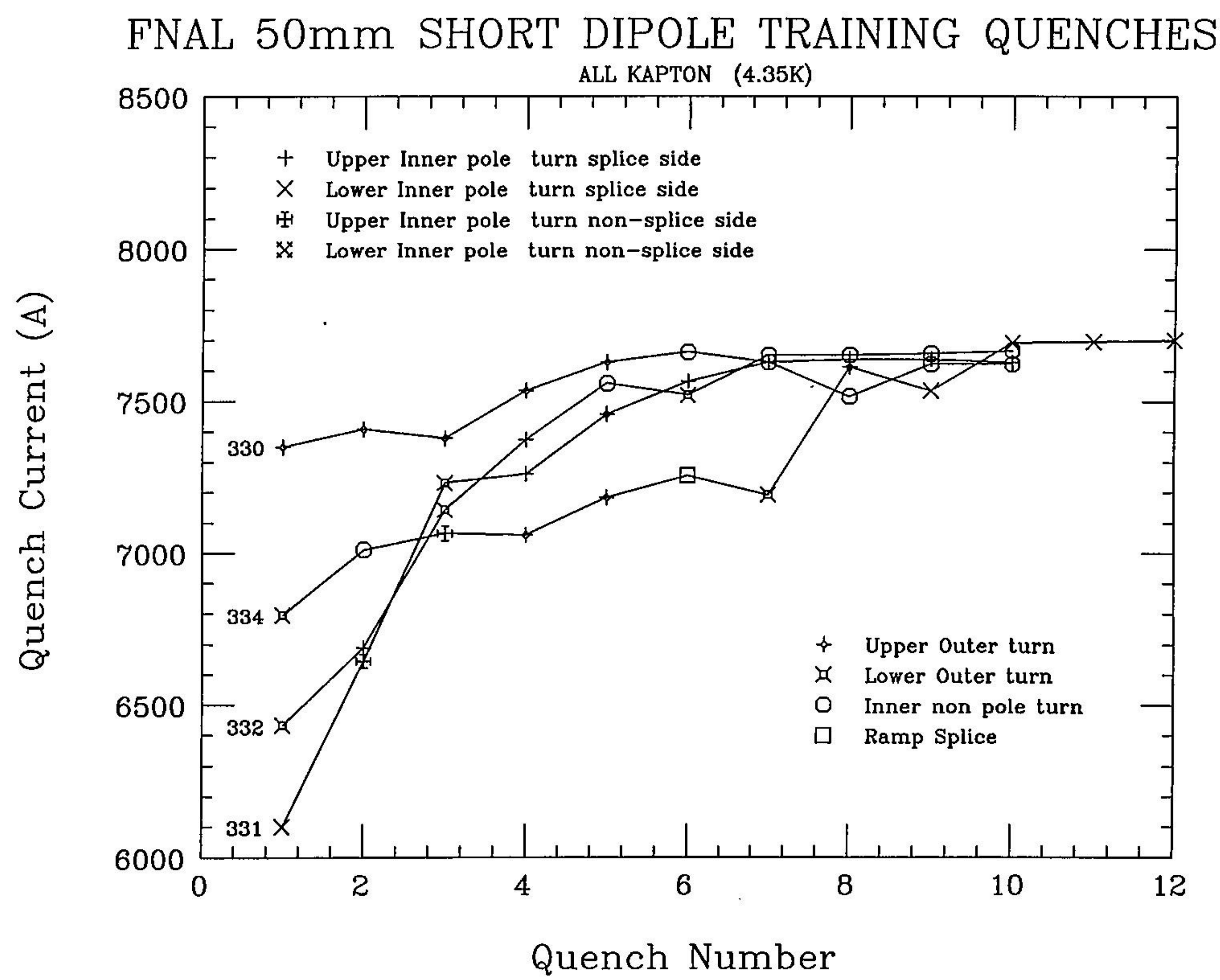

FNAL 50mm SHORT DIPOLE TRAINING QUENCHES
KAPTON/GLASS (4.35K)
Quench Current (A)
Quench Number
8500
8000
7500
7000
6500
6000
0
2
4
6
8
10
12
329
328
323
324
326
321
323B
329B
Upper Outer turn
Lower Outer turn
Inner non pole turn
Ramp Splice
Upper Inner pole turn splice side
Lower Inner pole turn splice side
Upper Inner pole turn non-splice side
Lower Inner pole turn non-splice side



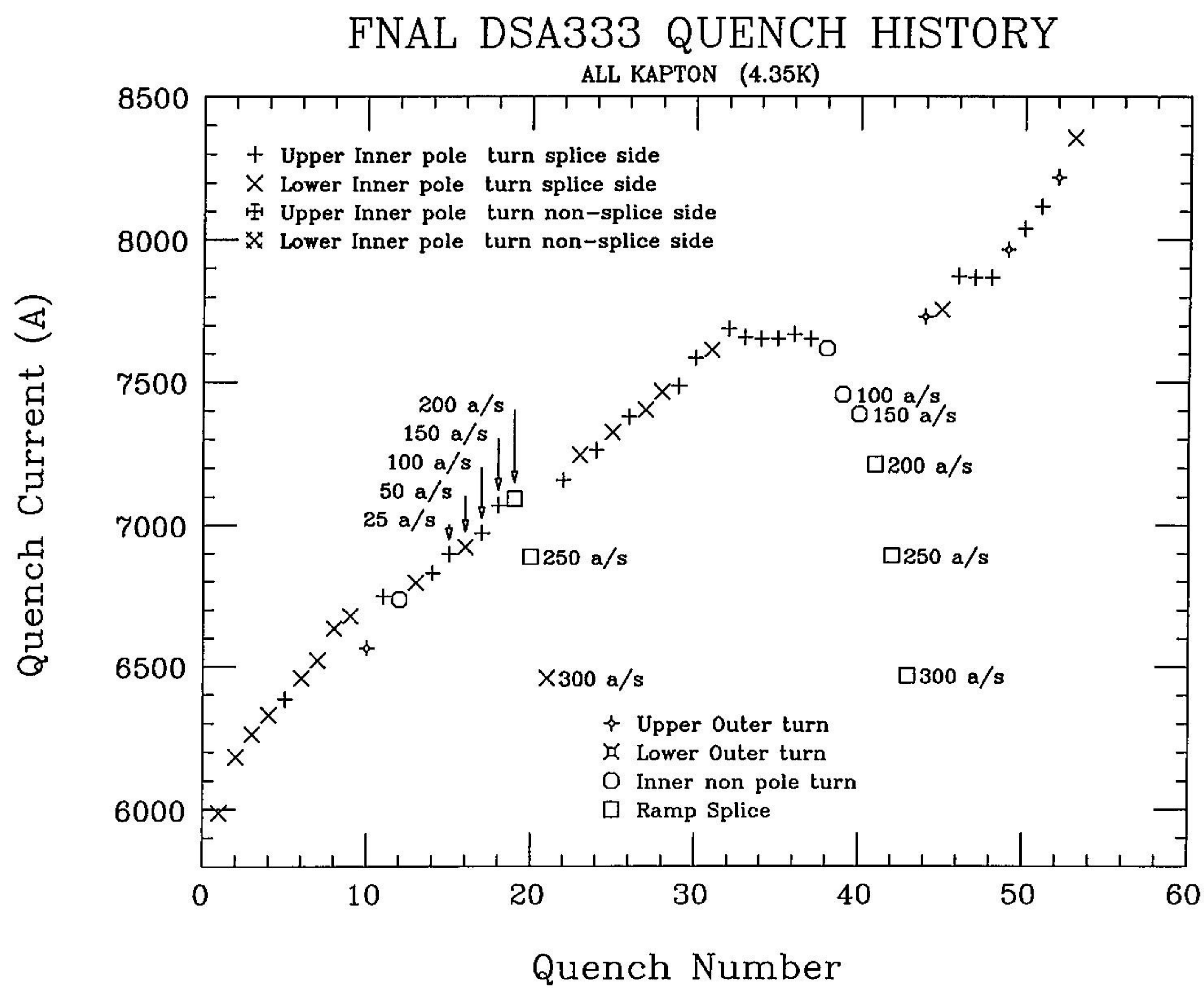
DSA323B_QUENCH_HIST_1.TOP



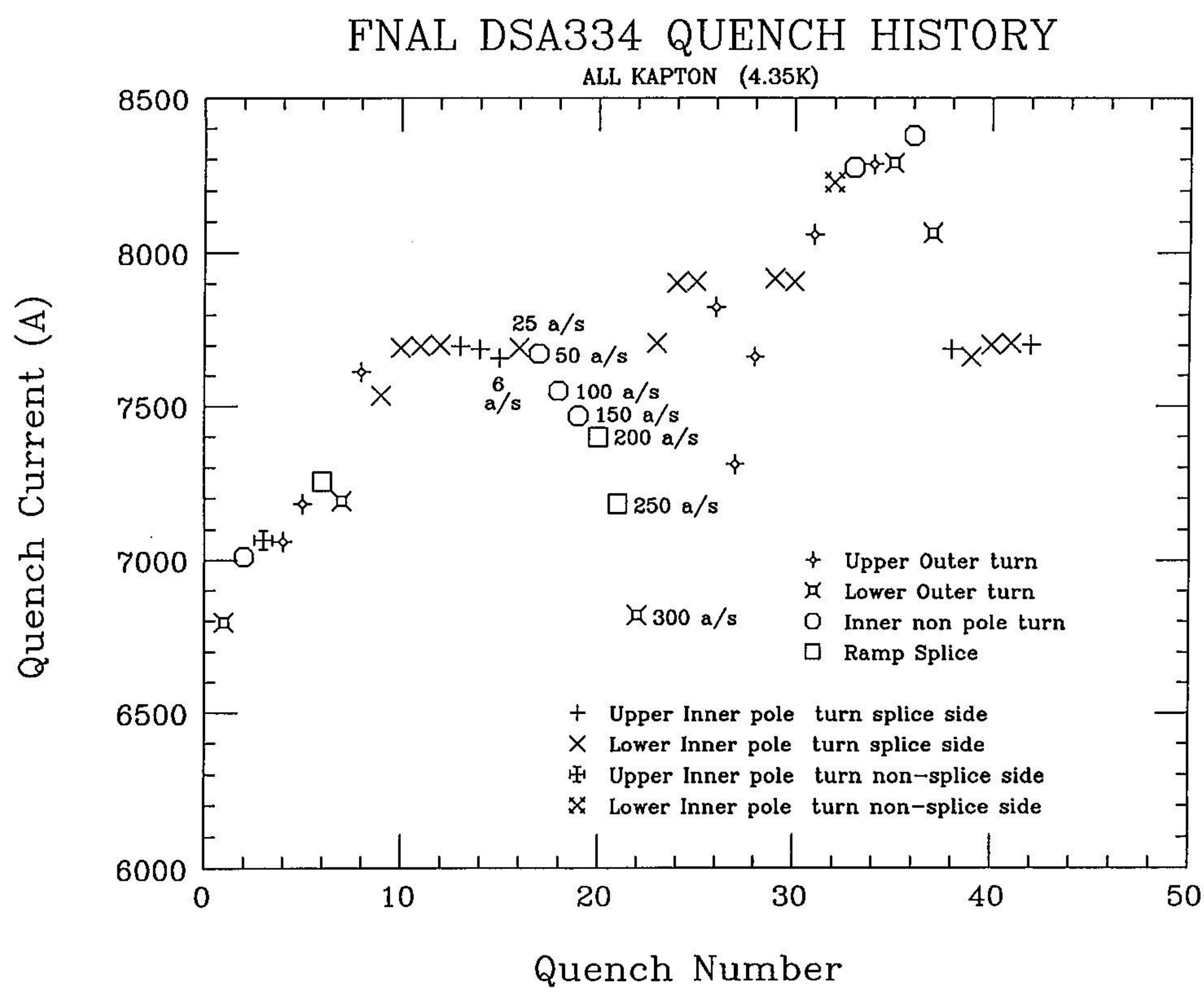
DSA329B_QUENCH_HIST.TOP



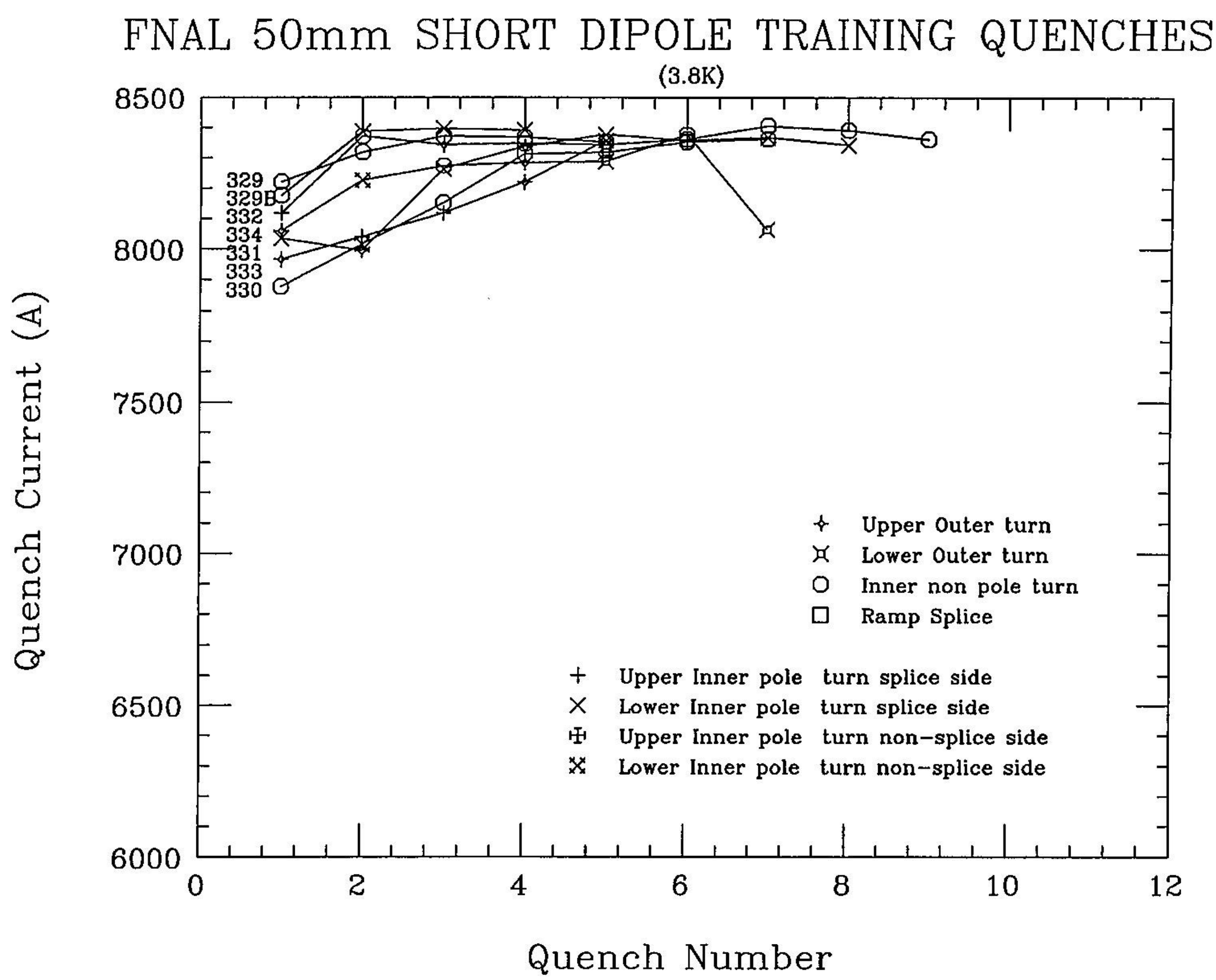
FNAL 50mm SHORT DIPOLE TRAINING QUENCHES
ALL KAPTON (4.35K)
Quench Current (A)
Quench Number
8500
8000
7500
7000
6500
6000
0
2
4
6
8
10
12
330
334
332
331
Upper Inner pole turn splice side
Lower Inner pole turn splice side
Upper Inner pole turn non-splice side
Lower Inner pole turn non-splice side
Upper Outer turn
Lower Outer turn
Inner non pole turn
Ramp Splice



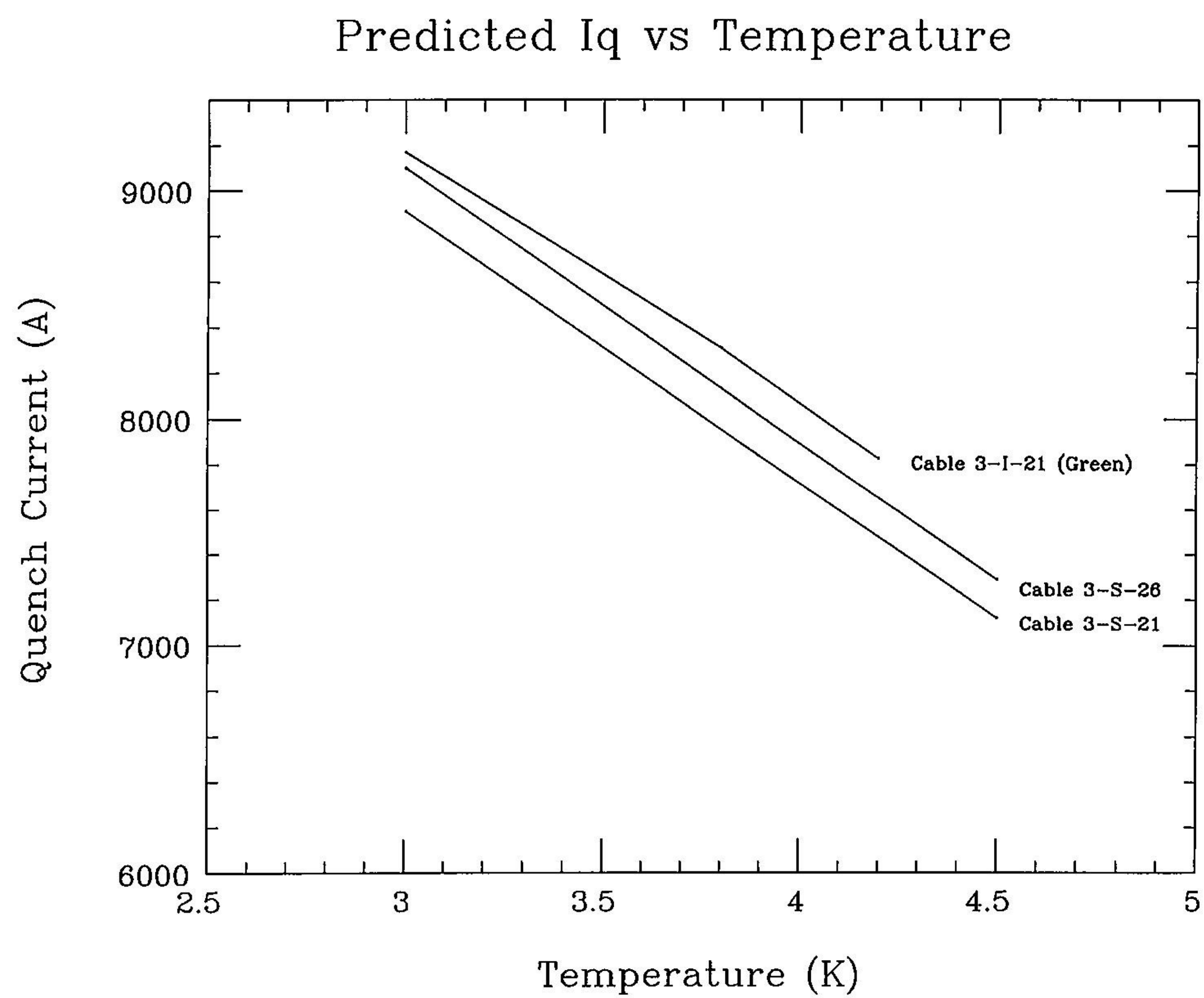
DSA333_QUENCH_HIST

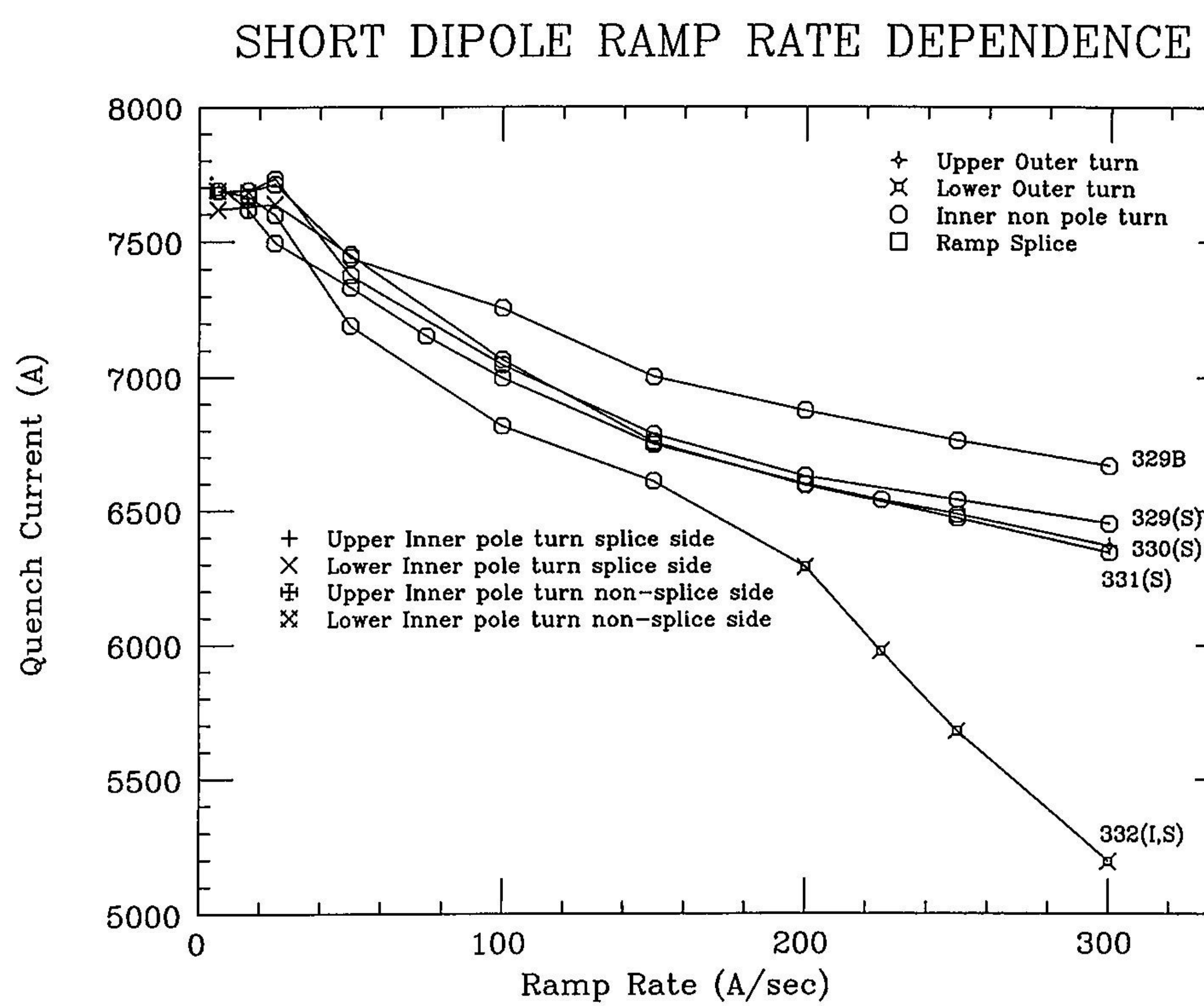


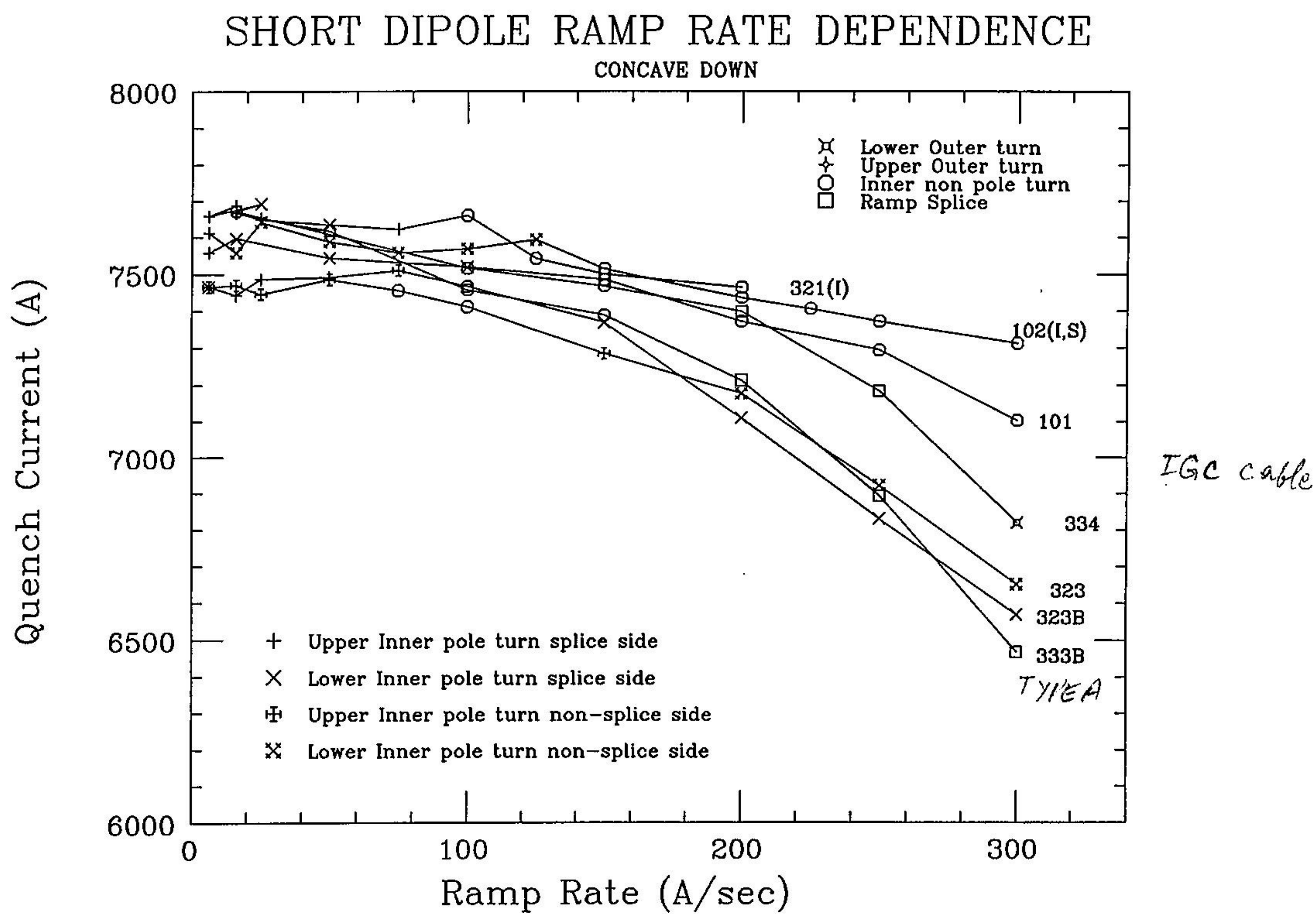
DSA334_QUENCH_HIST.TOP



FNAL 50mm SHORT DIPOLE TRAINING QUENCHES
(3.8K)
Quench Current (A)
Quench Number
8500
8000
7500
7000
6500
6000
0
2
4
6
8
10
12
329
329B
332
334
331
333
330
Upper Outer turn
Lower Outer turn
Inner non pole turn
Ramp Splice
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


Predicted Iq vs Temperature
Quench Current (A)
Temperature (K)
Cable 3-I-21 (Green)
Cable 3-S-26
Cable 3-S-21
9000
8000
7000
6000
2.5
3
3.5
4
4.5
5


SHORT DIPOLE RAMP RATE DEPENDENCE
Quench Current (A)
Ramp Rate (A/sec)
8000
7500
7000
6500
6000
5500
5000
0
100
200
300
Upper Outer turn
Lower Outer turn
Inner non pole turn
Ramp Splice
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
329B
329(S)
330(S)
331(S)
332(I,S)



DCHART
DSA_RRATE-CAVE-DOWN.TOP

Studies of AC Losses and Ramp Rate Dependence of 1.5m Model SSC Collider Dipole Magnets at Fermilab

10/27/92

Joe Ozelis
FNAL

AC Loss measurements were performed on several of the 1.5m model SSC dipole magnets built by Fermilab, with the following objectives in mind :

- **Define operational limits for SC magnets under AC operation**

- **Provide useful design information for the magnets to be built for the SSC HEB (High Energy Booster)**

- **Provide a means for correlating measured eddy current losses with ramp rate effects on quench current**

How is this to be done ?

Energy losses in SC magnets can be observed *electrically* as the difference between energy injected into the magnet and energy extracted from the magnet during a ramp cycle. ⟶ EI/EO

Integration of the product of magnet voltage and current over a closed ramp cycle yields this energy difference :

$$U = \oint (V(t) \cdot I(t))dt$$

INTEGRATE OVER A CLOSED CYCLE SO $I_i = I_f$

Where do these losses come from ? What is the mechanism that leads to an energy loss in a superconducting magnet ?