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Quench Performance and Multipoles of DSS6

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QUENCH PERFORMANCE AND MULTIPOLES OF DSS6

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SUMMARY. The principal characteristics of this magnet are: 1.8m length, C358A coil cross section, 1.6:1 Cu:SC ratio, coil ends filled with alumina-epoxy mix, no iron over coil ends or last 2.6 inches of inner coil straight-section. The magnet exhibited little training as the temperature was progressively lowered from 4.5K (6.6T) to 4.0K (7.1T) and then to 3.5K (7.5T). The magnet required no retraining after a thermal cycle to room temperature. (Difficulties with the "repressurization" procedure introduced a small amount of uncertainty in conclusions about training at 4.0K and below.) The allowed multipoles were small and consistent with those of DSS4 and DSS5, as expected. The unallowed terms were consistent with those expected from construction errors.

QUENCH PERFORMANCE. An extract from the training history (Fig. 1) summarizes the principal features of the tests. The magnet required one or two training quenches to reach the plateau of 6.58T (6470A) at 4.49K. The magnet required no retraining after a thermal cycle. As the temperature was progressively reduced to 4.0K and 3.5K only one or two training quenchs were required to reach the plateau fields of 7.07T (7030A) and 7.50T (7520A). At all three temperatures, the quench current plateau was about 1.02 times the calculated short-sample limit of the conductor, the same as for other magnets of this cross section. (It is possible that quenches made in the "repressurization" mode, discussed below, helped train the magnet at temperatures of 4.0K and below.)

Three quenches in the lower outer coil, at currents about 1% below the plateau, were seen at 4.5K. These are quite unusual at this temperature. The cable used in the outer coils was from the same spool as the cable for DSS4 and DSS5, which had no outer coil quenches.

When the ramp rate was raised from the usual 8A/sec to hundreds of amps/sec, the quench currents varied in the expected way. At 520A/sec, the quench current declined by 900A, but for 200A/sec and 100A/sec, the quench currents were several tens of amps higher than at 8A/sec. (The ramp-rate studies are shown in the complete quench history of the magnet, Fig. 2a and 2b. The ramp-rate shown as a nominal 400A/sec in Fig. 2a was measured to be 520A/sec.)

About half the quenching at and below 4.0K was done with the helium "repressurized" to half or more of an an atmosphere before the quench. This technique, first used with DSS4, was adopted to increase the resistance to electrical breakdown. However, sufficient experience with the method was gathered during the quenching of this magnet to indicate that temperature gradients large enough to affect the quench currents of the magnet were present after repressurization. This is clearly seen in quenches at 3.5K (quenches 46-59, Fig. 2b), where repressurization quenches were done before and after a series of standard quenches. The repressurization quenches yielded erratic performance whereas the standard quenches had a quite stable plateau at 7.5T with r.m.s. variation 14A. (The 3.5K temperature was chosen as the lowest that seemed to be safe for standard quenches. It corresponds to about 1/3 of an atmosphere. An informal poll indicates that 7.5T is a sufficiently high field for demonstrating reserve in the magnets.)

The repressurization quenches at 3.0K cloud the training of the magnet at 4.0K and 3.5K. The highest field reached at 3.0K was 7.3T, higher than the plateau of 7.1T at 4.0K but not as high as the 7.5T plateau at 3.5K. It is possible that the quenching at 3.0K reduced the training necessary at 4.0K and 3.5K.

Quench 60 is a low-field quench (4.5T) which is not understood. It occurred during the down-ramp of an AC cycle to 5.3kA, prior to magnetic measurements. The AC cycle was the first run of the day and was at 3.5K. The magnet performance during the following measurement run to 7.5T was fine. In view of the excellent performance of the magnet during standard quench runs at 3.5K, this quench was attributed to unknown conditions in the dewar.

MULTIPOLES. The standard report of multipoles is contained in TMG 370. The focus here is on comparison with similar magnets and SSC requirements. In evaluating the allowed multipoles, allowance must be made for the 2-3 mil difference between the design and actual size of the assembly shims used in the magnet. In order to compare the magnet to DSS4 and DSS5, the measured values have been corrected for the difference in shim size. The sextupole has been increased by 2.3 units and the measured decapole has been reduced by 0.3 units. These corrected values, together with the measured values from DSS4 and DSS5, are given in Table I. The multipoles have been averaged over up and down ramps from 2kA through 3kA. The SSC required systematic and expected random construction errors are also given in the Table. The following conclusions may be drawn:

(1) The allowed multipoles need to be adjusted. The sensitivity of the multipoles to shim size indicates that adjustments in the coil cross section will probably be at the level of a few mils.

(2) The magnet-to-magnet reproducibility is better than expected. This last conclusion is tempered by the fact that the cable used in DSS4, 5 and 6 all came from the same spool.

(3) The calculated and measured values of the transfer function B/I agree within 5 parts in 10,000. The transfer function for DSS6, corrected by 0.01 G/A for shim differences, is larger than that of DSS4 and DSS5 by a part in 1000.

Measurements of the unallowed multipoles may have contributions from the allowed terms if the measuring coil is not centered in the magnet. The previous method for determining the position of the measuring coil (interpreting a7 and b7 as due to feeddown from b8) cannot be used because b8 is so small for these

C358A coils. Thus, there is no way to correct for possible feeddown from the allowed multipoles. However, the allowed terms vary sufficiently due to magnetization effects that currents at which they are very close to zero can be found. For b2, b6, and b8, it was possible to find currents at which these multipoles were sufficiently small that feeddown due to a 2mm (a "typical maximum") displacement of the measuring coil was less than 0.02 units.

Measurements of b4 did not yield a value sufficiently close to zero for negligible feeddown. However, b4 did cross zero between two consecutive measurements. The unallowed terms were plotted against b4, allowing them to be determined by linear interpolation. Following this procedure for three separate runs gave an idea of the scatter due to measurement error. An example of this procedure is given in Fig. 3.

Results for all the unallowed terms are given in Table II. The Table also presents the estimated uncertainty in the values. The unallowed terms are compared to the SSC average and r.m.s. construction error tolerances in Table III. For this single magnet, the measured multipoles are consistent with the estimated construction tolerances and, therefore, with acceptable unallowed systematic multipoles. (In the case of the quadrupole, comparison is made to the expected tolerances for magnets where there is no shimming of the collared coil in the yoke.)

This method was not used on DSS4 and DSS5 because the measuring coil used in DSS6 had much better reproducibility than the magnets coil used in the earlier magnets (cf. report MTG 371). For example, sextupole measurements of DSS6 made one day apart differed by at most 0.01 unit.

dss6report.txt (bnldag::)

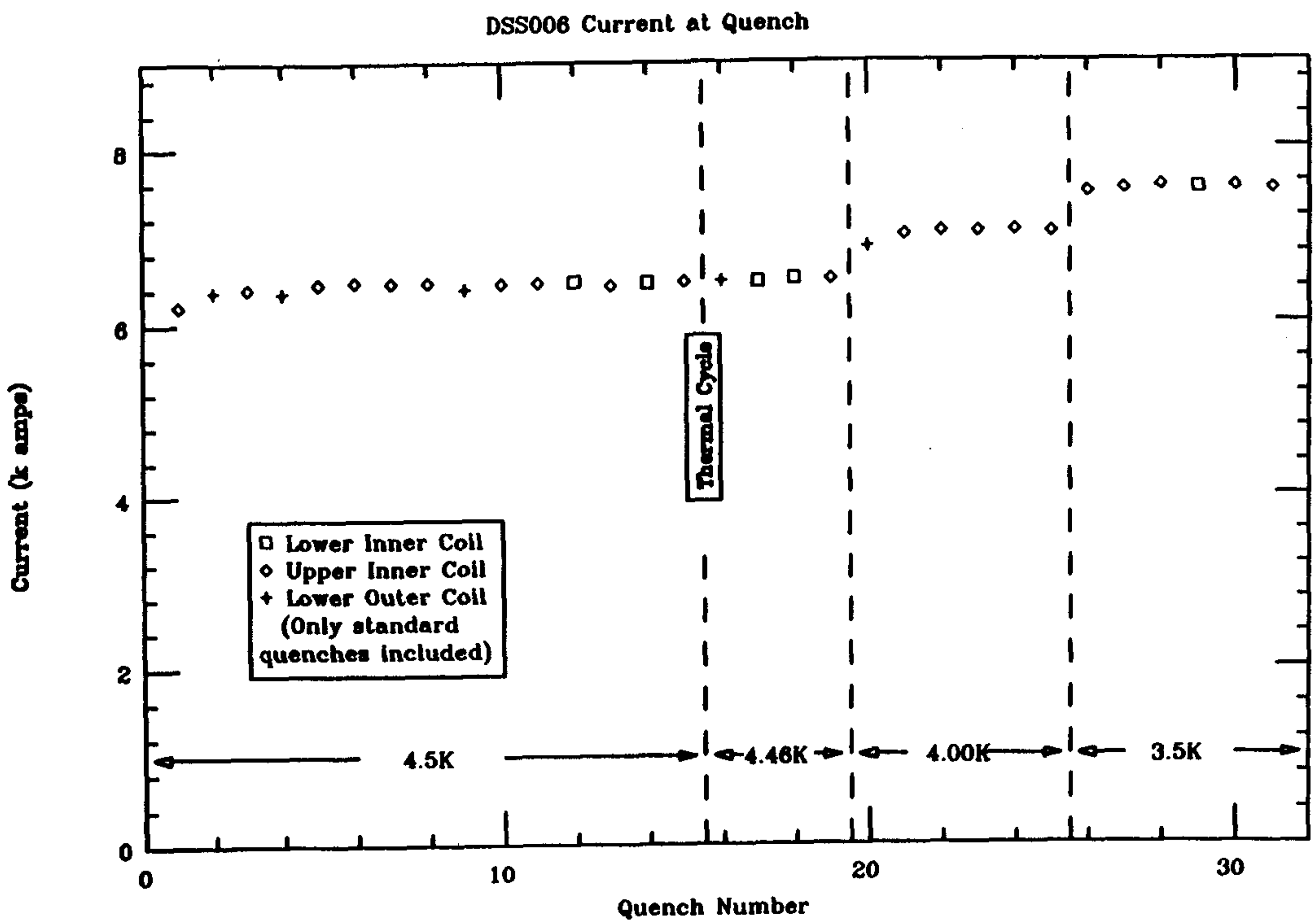
DSS006 Current at Quench
Current (k amps)
Quench Number
0
2
4
6
8
0
10
20
30
Thermal Cycle
□ Lower Inner Coil
◇ Upper Inner Coil
+ Lower Outer Coil
(Only standard
quenches included)
4.5K
4.46K
4.00K
3.5K

FIG. 1

DSS006 Initial Test $\dot{I} = 8\,A/sec$ $T \sim 4.4 - 4.5\,K$

1.8 m SSC dipole

1.6:1 = Cu:Sc   Same cable # as DSS004, 005

"filled ends" (alumina/epoxy mixture)   G11 "shoe"

no iron over coil ends B_{ss} calc. (at 4.49 K) includes self-field effects in short-sample meas.

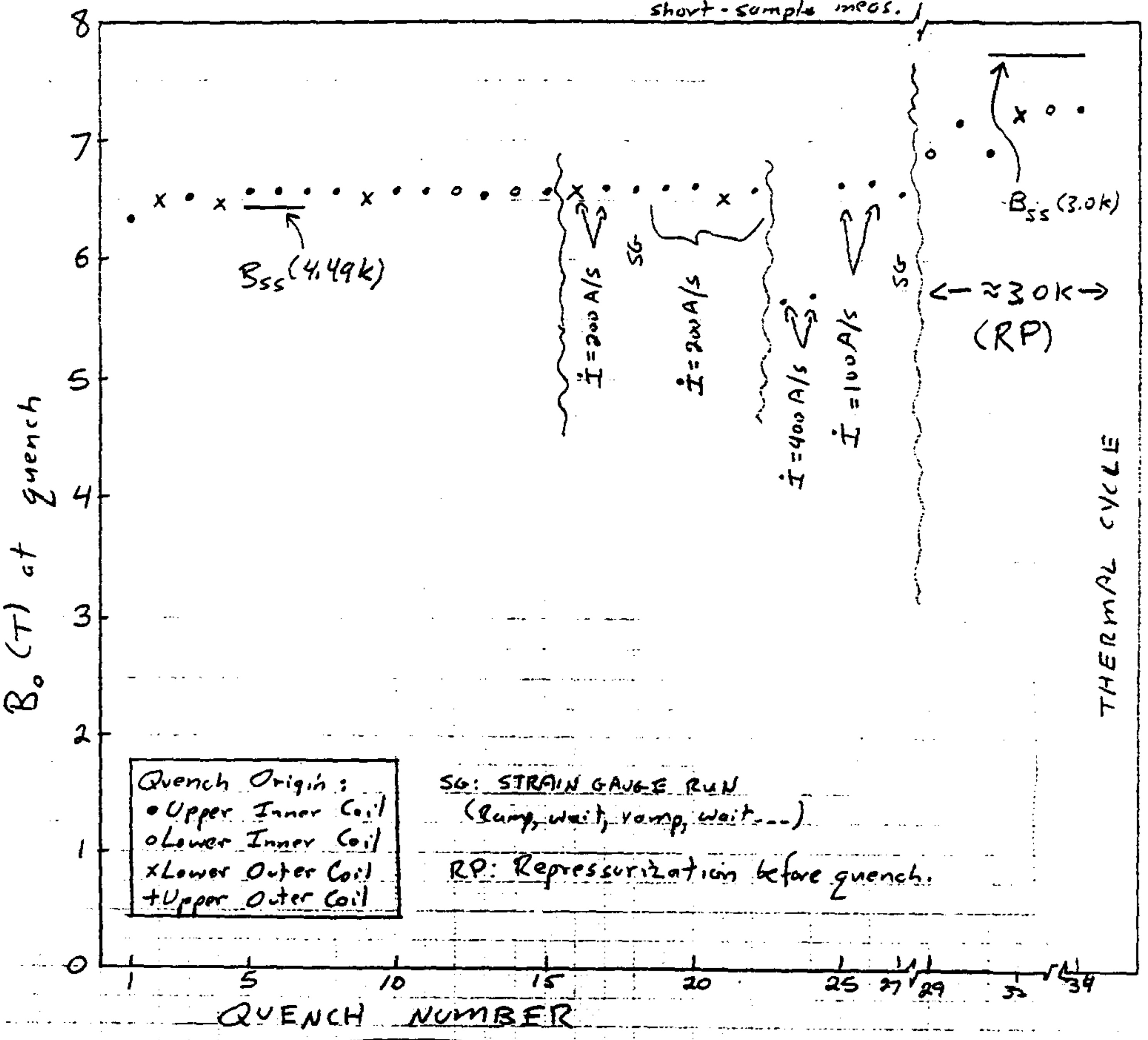

Fig 2a

PW Oct 16, '87

DSS006 Thermal Cycle

$\dot{I}$ = 8 A/sec
T ~ 4.4 - 4.5 K

Quench #35 is first quench following cycle 4.5 K → R.T. → 4.5 K

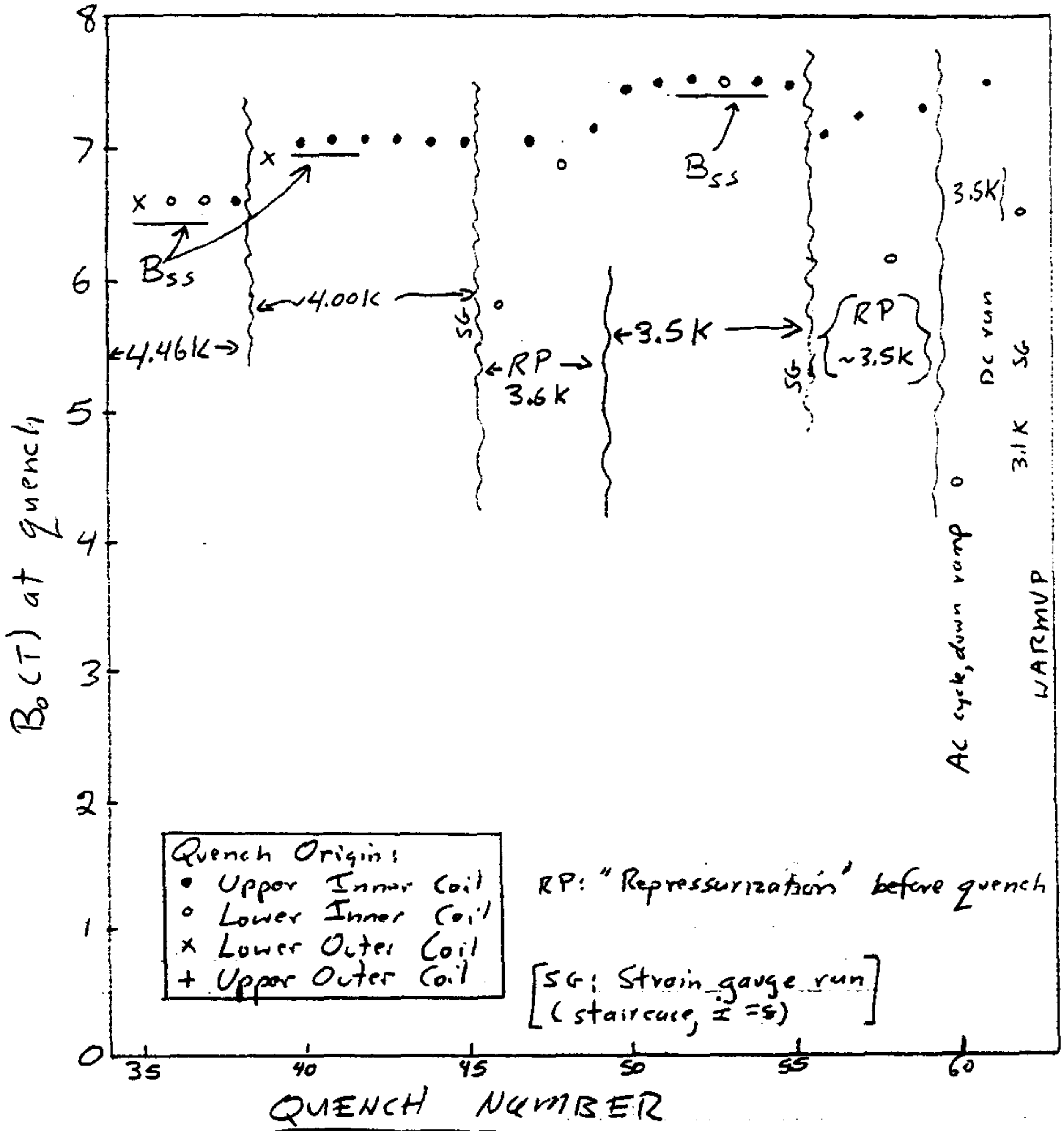

FIG. 2b

PW 10/30/87

DSS6: a_3 vs. b_4

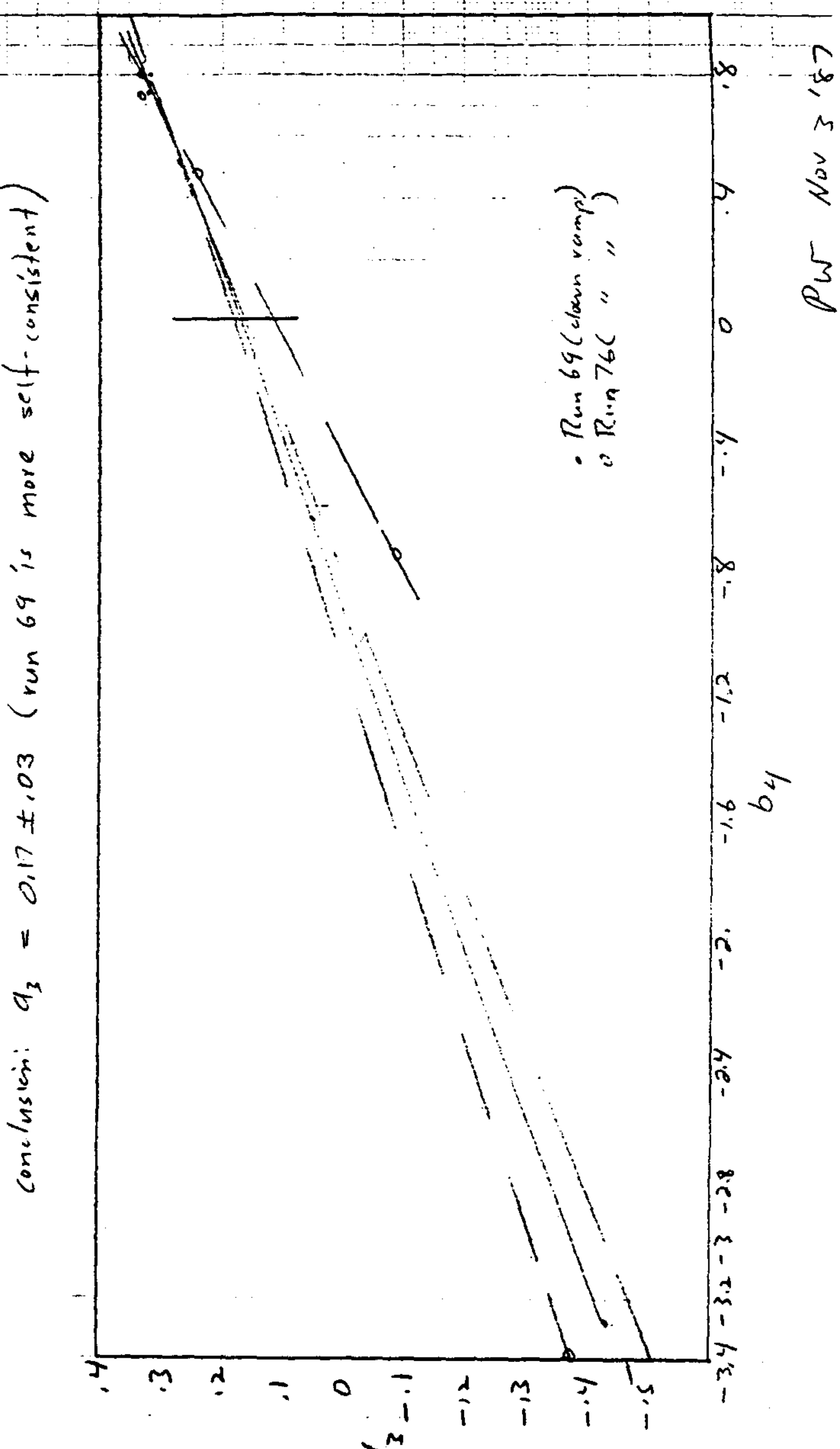

FIG. 3

DSS 4/5/6 ALLOWED MULTIPOLES [3]

POLE	MEASURED			MEAS. MEAN ± σ	C358 design	SSC Req.	
	DSS4	DSS5	DSS6 [1]			Avg.	σ's
b_2	2.5	2.0	3.5	2.7±0.8	-.03	1.0	2.0
b_4	0.54	0.40	0.51	0.48±0.07	-.03	0.2	0.7
b_6	-0.07	-0.09	-0.07	-0.08±.01	0.00	0.04	0.2
b_8	0.06	0.07	0.06	0.06±.01	0.00	0.1	0.1
b_{10}	0.07	0.08	0.06	0.07±.01	0.08	–	–
b_{12}	-0.02	-0.02	-0.01	-0.02±.01	-0.01	–	–
B/I	10.429	10.429	10.438	10.432±.005	10.426 [2]	–	–

↑ $5\times10^{-4} = \delta(TF)/TF$

CONCLUSION: (ONLY 3 MAGNETS; ALL SAME SPOOL)

ⓐ SYSTEMATICS NEED ADJUSTMENT

(~0.5 unit b_2 = 1 mil shim = ~0.1 unit b_4 = ~.02 unit

ⓑ σ's GREAT!

[1] DSS6 meas. values adjusted for use of non-design shims by +2.3 units b_2, -0.27 units b_4, +0.05 units b_6.

[2] C358A design × 1.003 (Thermal contraction of iron)

[3] Averaged over up + down ramps, 2-3 KA

TABLE I

P.W. MSIM
4 NOV '87

UNALLOWED MULTIPOLES - DSS6

Analysis problem - feeddown, lack of b_8 for determining measuring coil location.

Solution - pick currents where allowed multipole b_n; small read off a_n, b_n; take note of magnitude of maximum feeddown from b_n.

(Remark - need good measuring coil since can't average over currents - new coil repeatability after 24 hours is 0.01 unit in b_2 - only used for DSS6.)

n	a_n	b_n	Comment
1	0.95	-1.06	feeddown ≤ 0.02 units
2	0.41		"
3	0.17 ± 0.03	-0.23 ± 0.02	plot a_3,b_3 us. b_4 near 0
4	0.02 ± 0.02		"
5	0.06	-0.05	feeddown ≤ 0.01 units
6	0.00		"

Higher order terms are ≤ 0.02 units

(Remark - systematics may be underestimated.)

TABLE II

DSS6 UNALLOWED MULTIPOLES

- Compare to tolerances*

	DSS6	Average	σ's
a_1	.95	.2	3.3 (0.7)[1]
a_2	.41	.1	.6
a_3	.17	.2	.7
a_4	.02	.2	.2
a_5	.06	-	.2
a_6	.00	-	.1
a_7	<.02	-	.2
a_8	<.02	-	.1
b_1	-1.06	.2	1.6 (0.7)[1]
b_3	- .23	.1	.3
b_5	- .05	.02	.1
b_7	<.02	.06	.2

CONCLUSION: O.K. as far as one can tell from one magnet

TABLE III

* Chao and Tigner, SSC-N-183 and (for quadrupole) SSC-7

1 Assuming shimming of collared coil in yoke.

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