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SSC Technical Note No. 14

COIL DESIGN FOR THE LBL-SSC PROTOTYPE DIPOLE (SSC-B61)

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A cross section has been developed for the prototype LBL 40 mm SSC dipole which appears to be acceptable from the standpoints of mechanical stability, field quality and central field. The dipole uses different conductors for the inner and outer layers as shown in Table I.

TABLE I. Conductor Properties

Layer	d_w (mils)	N_w	Cu/SC	W_1 (mils)	W_2 (mils)	Δr (mils)
Inner	31.8	23	1.3/1	51.6	62.2	366
Outer	25.5	30	2.0/1	40.3	51.6	383

d_w is the wire diameter, N_w is the number of wires in the cable, Cu/SC is the copper to superconductor ratio, W_1 and W_2 are the measured bare cable azimuthal widths at the inner and outer edges, and Δr is the bare cable radial dimension.

The coil cross section uses 2 wedges in the inner layer and 1 wedge in the outer layer as indicated in Figure 1.

TABLE II. Coil Cross Section (R_{FE} = 4.392 cm)

Layer	Turns	r_i (cm)	r_o (cm)
Inner	5,8,4	2.002	2.931
Outer	12,9	2.951	3.923

The partially keystoned conductor turns have "reference radii" r_i and r_o given in Table II. The midpoint of the outer bare edge of each conductor turn in the inner layer is forced to lie on a reference radius and similarly for the inner edge of the outer layer.

The actual coordinates of each turn and their azimuthal angles from the center of the aperture are shown in Figure 2. The iron model is shown in Figure 3. The multipoles at 1 cm are given in Table III.

TABLE III. Multipoles, $b_n \times 10^4$ @ 1 cm

I (A)	TF	b_1	b_2	b_3	b_4	b_6	b_8	b_{10}
$\infty\mu$	12.48	0.0	0.0	0.0	−0.1	0.0	0.5	0.1
1000	12.43	6.1	−3.9	0.0	0.0	0.1	0.5	0.1
5000	11.95	1.3	2.7	0.1	0.4	0.0	0.5	0.1
6000	11.61	0.4	0.7	−0.1	0.4	0.0	0.5	0.1

The data in the row marked $\infty\mu$ are analytic results from the optimization program. The data in the other three rows are results from MDP.

The magnet central field and current margins were determined using the J_c curve in Figure 4. The $J_c(B,T)$ behavior was assumed to follow the parameterization given by Morgan(1) with constants appropriate to NbTi. The curve was normalized to a value of 2400 A/mm^2 at 5 T and 4.2 K as given by Clyde Taylor. Then the I_c versus B behavior at 4.5 K was determined using the procedure outlined in Table 4 to get the effective area of NbTi.

TABLE IV. Critical Current Factors

Layer	Aw (mm^2)	Nw	e	df	A (mm^2)
Inner	0.5124	23	0.4348	0.85	4.355
Outer	0.3295	30	~~0.3333~~ .3571	0.85	~~2.8007~~ 3.000

e is the superconductor fraction, df is a degradation factor which arises from cabling, and A is the effective area including the factor df.

Cu/Sc 1.8:1

The central field and current margins can then be determined by examining the peak fields in the inner and outer layers at a given current. The peak field point (B_p) was assumed to be the uppermost corner of conductor on the inside edge. (The actual peak field point is believed to lie a small distance inside the conductor so these results may be slightly optimistic.) Table V shows the margins and central field (B_o) for MDP runs at 5000 and 6000 A.

TABLE V. NbTi Current Margins @ 4.5 K

	INNER COIL			OUTER COIL			
I (A)	B_p (T)	I_c (A)	Margin (%)	B_p (T)	I_c (A)	Margin (%)	B_o (T)
5000	6.19	6750	35	5.04	5900	18	5.97
5400	~6.61	5900	9	~5.37	5500	2	~6.37
6000	7.24	4750	-21	5.87	4850	-19	6.97

Interpolating between these two points it appears that the magnet will quench around 5400 A and achieve a central field of around 64 kilogauss. The performance is limited by the outer coil conductor since the inner coil has ~ 7% excess margin at this current.

1) G. Morgan, Estimating Nb_3Sn cable parameters, Analysis Section Note 42, 1983.

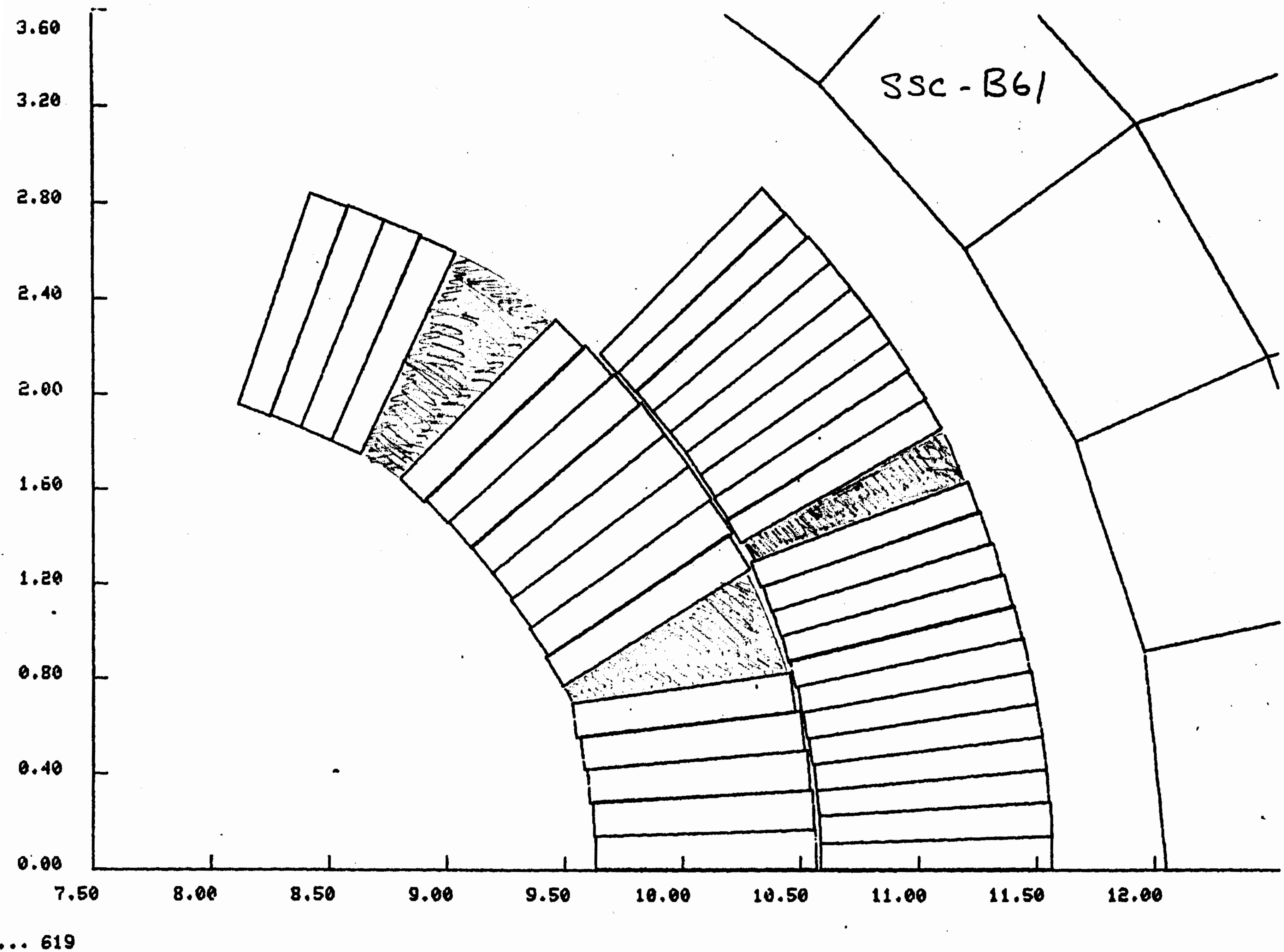
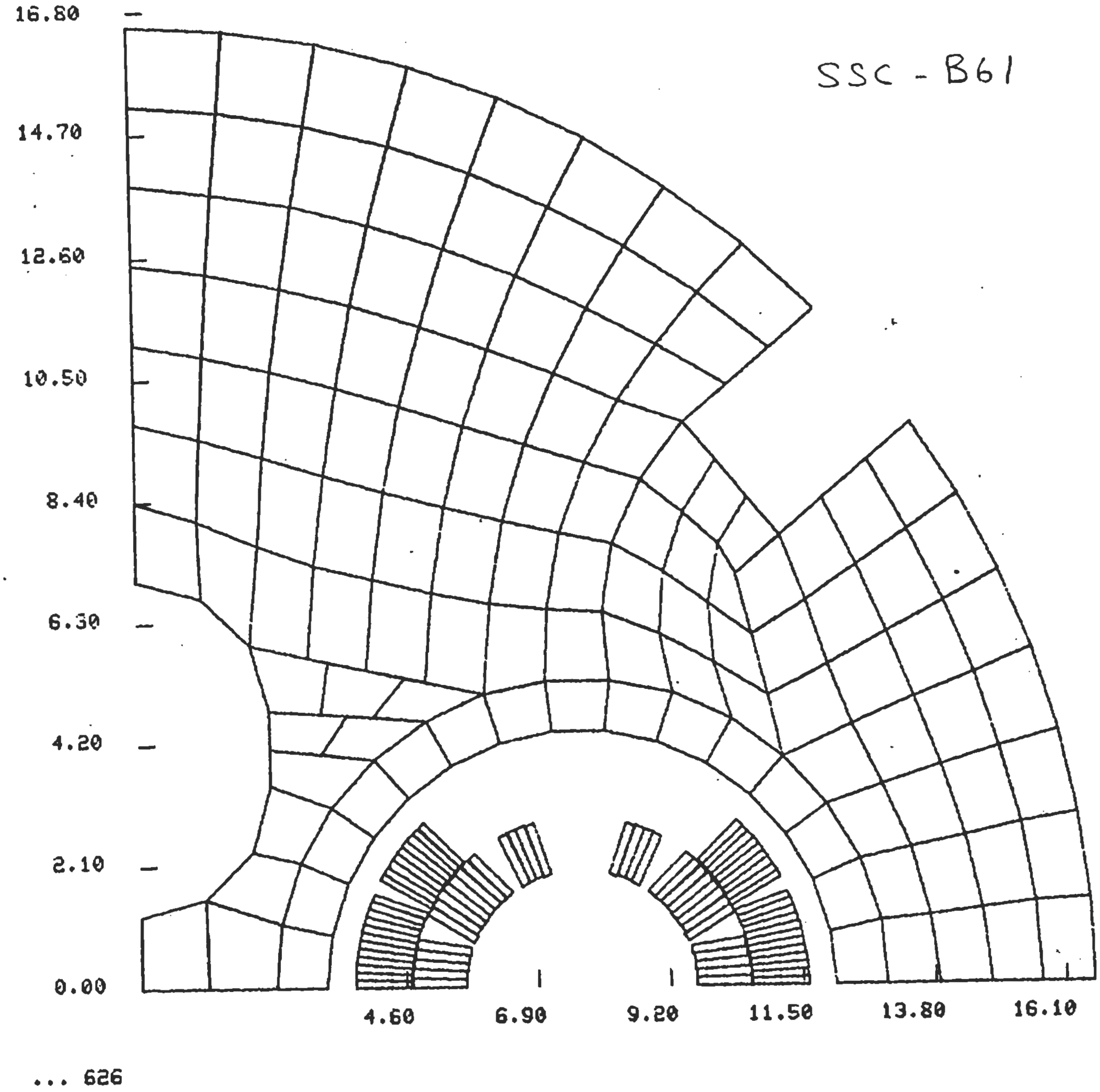

SSC-B61
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0.00
7.50
8.00
8.50
9.00
9.50
10.00
10.50
11.00
11.50
12.00
... 619

Figure 1

SSC-B61

Block	Turn	x (corner 1)	y (corner 1)	x (corner 2)	y (corner 2)	x (corner 3)	y (corner 3)	x (corner 4)	y (corner 4)	ϕ_1	ϕ_2	ϕ_3	ϕ_4
1	1	2.001	.0076	1.9997	.1463	2.9284	[illegible]	2.9308	.0076	.22	4.18	3.39	.15
1	2	1.9947	.1461	1.9887	.2847	2.9162	.3385	2.9234	.1731	4.19	8.15	6.62	3.39
1	3	1.9791	.2841	1.9691	.4225	2.8947	.5031	2.9067	.3380	8.17	12.11	9.86	6.63
1	4	1.9550	.4212	1.9409	.5592	2.8638	.6667	2.8806	.5019	12.16	16.07	13.10	9.88
1	5	1.9222	.5570	1.9042	.6945	2.8236	.8287	2.8451	.6645	16.16	20.04	16.36	13.15
.0390		2.0130		2.9310									
2	.2458E+01												
3	1	1.8656	.7727	1.7910	.8896	2.5669	1.4006	2.6560	1.2610	22.50	26.41	28.62	25.40
3	2	1.8025	.8971	1.7245	1.0118	2.4853	1.5452	2.5784	1.4082	26.46	30.40	31.87	28.64
3	3	1.7320	1.0171	1.6508	1.1295	2.3958	1.6846	2.4928	1.5504	30.42	34.38	35.11	31.88
3	4	1.6544	1.1322	1.5699	1.2422	2.2986	1.8187	2.3994	1.6873	34.39	38.35	38.35	35.12
3	5	1.5699	1.2422	1.4823	1.3497	2.1939	1.9471	2.2986	1.8187	38.35	42.32	41.59	38.35
3	6	1.4788	1.3468	1.3881	1.4517	2.0821	2.0694	2.1904	1.9441	42.32	46.28	44.82	41.59
3	7	1.3813	1.4456	1.2876	1.5478	1.9634	2.1854	2.0753	2.0633	46.30	50.24	48.06	44.83
3	8	1.2776	1.5384	1.1810	1.6379	1.8380	2.2948	1.9534	2.1760	50.29	54.21	51.31	48.09
4.2067		2.0083		2.9310									
4	.5542E+01												
5	1	1.0119	1.7350	.8860	1.7932	1.2636	2.6421	1.4139	2.5726	59.75	63.71	64.44	61.21
5	2	.8878	1.7974	.7603	1.8519	1.1132	2.7114	1.2655	2.6463	63.71	67.68	67.68	64.44
5	3	.7603	1.8519	.6313	1.9027	.9591	2.7721	1.1132	2.7114	67.68	71.65	70.91	67.68
5	4	.6297	1.8985	.4992	1.9455	.8017	2.8240	.9575	2.7678	71.65	75.61	74.15	70.92
5.6083		2.0032		2.9310									
1	1	2.9511	.0076	2.9495	.1177	3.9212	.1464	3.9233	.0076	.15	2.29	2.14	.11
1	2	2.9484	.1177	2.9435	.2277	3.9139	.2851	3.9201	.1464	2.29	4.42	4.17	2.14
1	3	2.9415	.2276	2.9334	.3374	3.9017	.4234	3.9119	.2849	4.42	6.56	6.19	4.17
1	4	2.9305	.3371	2.9192	.4466	3.8845	.5612	3.8988	.4231	6.56	8.70	8.22	6.19
1	5	2.9155	.4462	2.9009	.5553	3.8624	.6983	3.8808	.5607	8.70	10.84	10.25	8.22
1	6	2.8964	.5547	2.8786	.6633	3.8365	.8346	3.8579	.6977	10.84	12.98	12.28	10.25
1	7	2.8732	.6624	2.8522	.7705	3.8036	.9700	3.8301	.8337	12.98	15.12	14.31	12.28
1	8	2.8460	.7692	2.8219	.8766	3.7670	1.1041	3.7975	.9687	15.12	17.26	16.34	14.31
1	9	2.8149	.8749	2.7875	.9816	3.7255	1.2369	3.7600	1.1024	17.27	19.40	18.37	16.34
1	10	2.7798	.9795	2.7493	1.0853	3.6793	1.3681	3.7178	1.2347	19.41	21.54	20.40	18.37
1	11	2.7408	1.0827	2.7072	1.1875	3.6284	1.4977	3.6708	1.3655	21.56	23.69	22.43	20.41
1	12	2.6979	1.1844	2.6612	1.2882	3.5729	1.6255	3.6192	1.4946	23.70	25.83	24.46	22.44
5.8304		2.9510		3.9199									
2	.1766E+01												
3	1	2.6172	1.3681	2.5614	1.4630	3.3921	1.9680	3.4624	1.8483	27.60	29.73	30.12	28.09
3	2	2.5640	1.4646	2.5054	1.5578	3.3208	2.0871	3.3947	1.9695	29.73	31.87	32.15	30.12
3	3	2.5072	1.5590	2.4459	1.6504	3.2453	2.2035	3.3226	2.0882	31.87	34.01	34.18	32.15
3	4	2.4470	1.6511	2.3830	1.7408	3.1657	2.3172	3.2464	2.2043	34.01	36.15	36.20	34.18
3	5	2.3833	1.7410	2.3167	1.8287	3.0821	2.4280	3.1661	2.3175	36.15	38.29	38.23	36.20
3	6	2.3164	1.8284	2.2472	1.9141	2.9946	2.5358	3.0818	2.4278	38.29	40.42	40.26	38.23
3	7	2.2463	1.9133	2.1746	1.9969	2.9033	2.6403	2.9936	2.5350	40.42	42.56	42.28	40.26
3	8	2.1730	1.9955	2.0989	2.0769	2.8083	2.7416	2.9017	2.6389	42.56	44.70	44.31	42.29
3	9	2.0967	2.0749	2.0202	2.1541	2.7097	2.8394	2.8061	2.7396	44.70	46.84	46.34	44.31
6.8367		2.9510		3.9226									

Figure 2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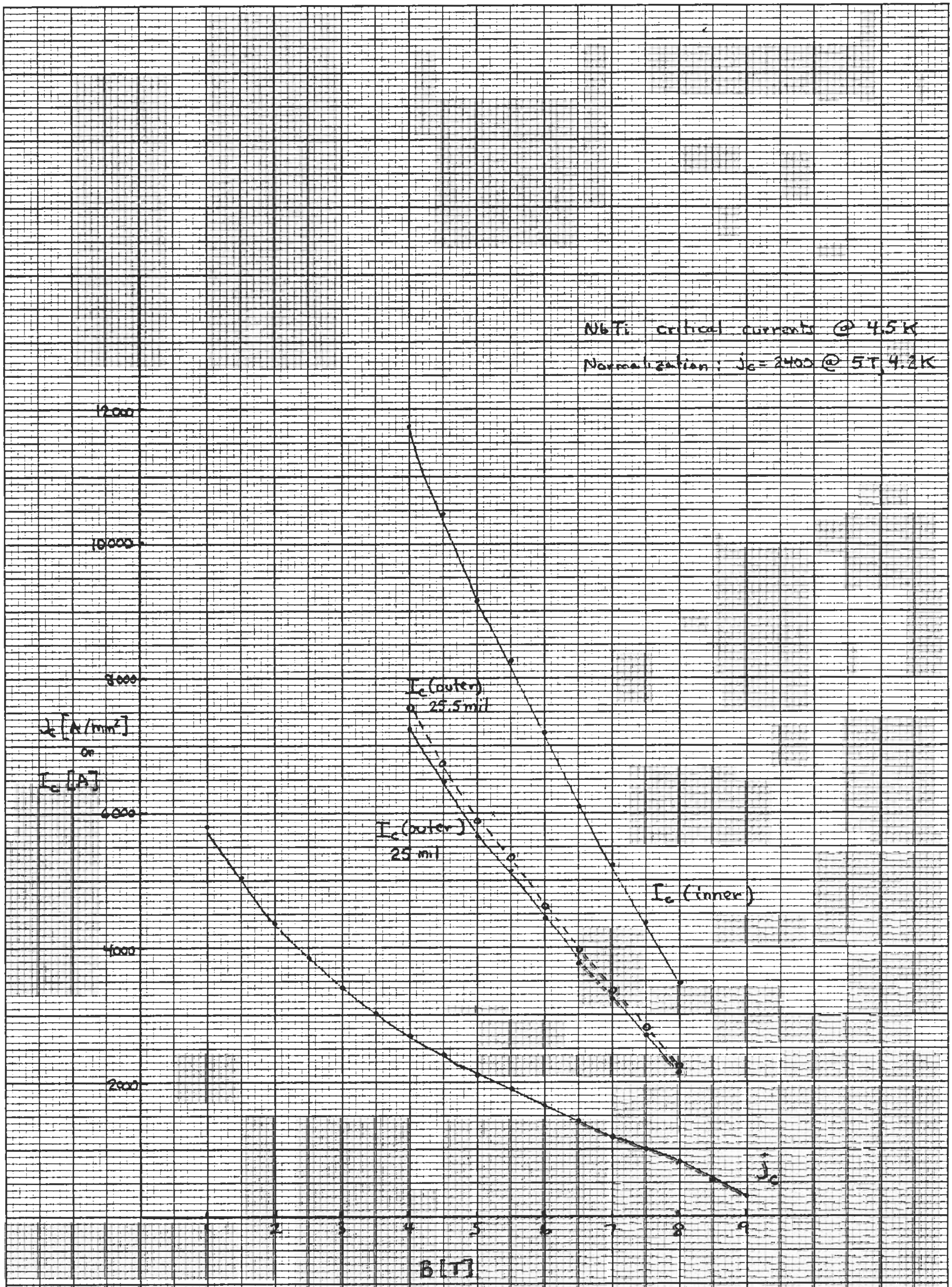
... 626

Figure 3



NbTi critical currents @ 4.5 K
Normalization: jc = 2400 @ 5T, 4.2K
12000
10000
8000
6000
4000
2000
jc [A/mm²] or Ic [A]
Ic (outer) 25.5 mil
Ic (outer) 25 mil
Ic (inner)
jc
1
2
3
4
5
6
7
8
9
B [T]

Figure 4

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