Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
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Upton, New York 11973

SSC Project

Technical Note No. 19

COIL DESIGN FOR THE 40 mm COLLARED SSC DIPOLE (SSC-C5)

R.C. Fernow and G.H. Morgan

October 8, 1984

A new 40 mm SSC dipole cross section has been designed which incorporates (1) new measurements of the cable dimensions and (2) a 15 mm non-magnetic collar between the coil and the aperture of the iron yoke. Different NbTi cables are used for winding the inner and outer coil layers as shown in Table 1. The first three columns give the wire diameter, number of wires in the cable, and copper to superconductor ratio. The last three columns give the compressed azimuthal width at the two edges and the radial extent. The Kapton-glass insulation is assumed to be 3 mils thick per side azimuthally and 6.5 mils thick per side radially.

Table 1

Layer	d_w (mils)	N_w	Cu/SC	W_1 (mils)	$\bar{W}$	W_2 (mils)	Δr (mils)
Inner	31.8	23	1.3/1	58.0	63.35	68.7	379
Outer	25.5	30	1.8/1	47.7	51.85	56.0	396

The coil cross section has two wedges in the inner layer and 1 wedge in the outer layer as shown in Table 2 and Figure 1. The partially keystoned conductor turns lie between the reference radii r_i and r_o given in Table 2. The midpoint of the outer edge of each conductor turn in the inner layer is forced to lie on the inner r_o, while the midpoint of the inner edge of each conductor in the outer layer lies on the outer r_i. The actual coordinates of each turn and their azimuthal angle from the center of the aperture are shown in Figure 2. The infinite permeability, room temperature multipoles shown in the first line of Table 3 are all below 1 10^{-4}.

A new 2-in-1 round iron cross-section was designed in collaboration with R. Leroy (drwg # 22-00.208-5). It has a 14 inch od and 6.5 inch center-to-center distance. A sizable stainless-steel strongback intrudes at top and bottom on the vertical centerline, and four 1.2 x 1.2 inch square cable slots are cut in radially at 40° from the horizontal axis. Two, 2 inch diameter he-

Table 2

Layer	Turns	r_i (cm)	r_o (cm)
Inner	6,7,3	1.999	2.962
Outer	8,12	2.987	3.993

Table 3

I (A)	Bo,G	Relative Bo/I	b_1	b_2	b_3	b_4	b_6	b_8	b_{10}
∞ μ	-	1.000	-	0.4	-	0.0	0.2	0.8	0.0
400	4124	.997	0.8	-0.9	0.2	0.0	0.2	0.8	0.0
5600	57243	.992	0.3	-0.8	0.1	0.0	0.2	0.8	0.0
6100	62203	.986	0.1	-0.4	0.0	0.0	0.2	0.8	0.0
6600	66903	.980	-0.6	-0.1	0.0	-0.1	0.2	0.9	0.0
7100	71397	.973	-1.7	-0.1	0.0	-0.1	0.2	0.9	0.0

lium coolant holes are centered on the vertical centerline, 1.447 inch from the median plane, as shown in Figure 3.

This iron configuration termed LBL09 was run at 5 values of current, one low and four high at 500 A intervals bracketing probable attainable values with NbTi and Nb_3Sn. The harmonics and transfer function are given in the balance of Table 3, as calculated using the program MDP. The decrease in b_1 at high field is thought to be real and due to greater saturation in the return leg than in the iron between the apertures. The 15 mm collar has the salutary effect of decreasing the effects of saturation on the allowed harmonics; the shifts in these are all less than one unit.

This commendable result is at the expense of a drop in transfer function (from 12.48 with the uncollared B61 design to 10.34 G/A in the present design). This results in an increase in quench current and a decrease in field. Table 4 gives the peak fields and corresponding critical currents for the cables of Table 1, assuming a superconductor performance specification of 2400 A/mm^2 at 4.2 K and 5 T, and assuming 15% loss in critical current due to cabling.

Table 4

Bo,T	$B_{peak,in}$	$B_{peak,out}$	Ic,in	Ic,out
6.12	6.40	5.27	6418	5992

The value for Bo is for the smaller critical current, 5992 A. In order to reach 65 kG, a current of 6398 A is required, corresponding to a bit over 2700 A/cm^2 at 4.2 K and 5 T with 15% degradation. At 6398 A, the current density in the outer copper is 1006 A/mm^2 and in the inner is 960 A/mm^2.

The stored energy per aperture at 6600 A is 63591 J/m and the inductance is 2.92 mHy/m per aperture. The stored energy is about 3% greater than that of the uncollared coil magnet at the same central field.

The coordinates of the center of each conductor and the forces acting there are given in Table 5; FR is the radial force and FTH the tangential force.

Finally, we note that with a central field of 6.5 T, the vertical field in the iron of the return leg is 2.24 T and the horizontal field between the apertures is 2.16 T. Since the saturation field, with the 2½% packing loss assumed (including gaps between blocks) is about 2.13 T, there is just sufficient iron vertically, and insufficient iron in the return legs. This is thought to be the cause of the negative b_1 term at I = 6100 and 7100 A given in Table 3. About 2.11 times as much flux crosses from one aperture to the other as returns in the outer leg. This number would be lower if the outer leg were unsaturated.

The contribution of the superconductor magnetization to the field harmonics at injection (0.325 T) was calculated using the method described in SSCTN17. In lieu of measurements on the actual cable, the magnetization for CBA NbTi was scaled with the following factors:

	Packing factor	Filament size	Cu/SC	Jc/Jc	Overall
inner	.809/.766	29/9	2.68/2.3	2700/2000	5.01
outer	.807/.766	23/9	2.68/2.8	2700/2000	3.30

The LBL material received for tests has a wire diameter of 25.5 mil and 23 micron filaments; the inner conductor filament size corresponding to this would be 31.8/25.5 times as large. A Jc of 2700 is the minimum needed to reach Bo = 6.5 T. The filament sizes can be reduced, as this is a worse-case analysis. The result is a B_o decrease of 22 G (69 x 10^{-4} B_o), Δb_2 = -36, Δb_4 = +1.7.

NO.	X,CM	Y,CM	BX,G	BY,G	FR,LB/IN	FTH,LB/IN
1	10.747	.088	-616.6	-44966.6	169.2	-2.3
2	10.737	.249	-2501.1	-45073.9	169.6	-9.4
3	10.717	.410	-4432.3	-45295.7	170.5	-16.6
4	10.686	.569	-6421.2	-45675.8	171.9	-24.0
5	10.646	.727	-8593.2	-46121.8	173.6	-32.2
6	10.596	.883	-11099.5	-46615.2	175.5	-41.6
7	10.397	1.282	-4838.7	-46127.4	173.6	-17.9
8	10.309	1.417	-7175.9	-48845.4	183.9	-26.7
9	10.212	1.546	-9511.6	-51238.6	192.9	-35.4
10	10.108	1.669	-11833.5	-53378.2	201.0	-44.1
11	9.996	1.786	-14122.1	-55386.8	208.5	-52.7
12	9.878	1.896	-16330.5	-57351.2	216.0	-61.0
13	9.752	1.998	-18453.8	-59539.7	224.2	-68.9
14	9.206	2.306	-9842.9	-52966.5	199.4	-36.5
15	9.055	2.362	-9642.0	-57764.9	217.5	-35.7
16	8.901	2.409	-9310.9	-62962.0	237.0	-34.3
17	11.758	.074	-868.0	-3090.3	11.6	-3.3
18	11.752	.206	-3272.0	-3295.4	12.4	-12.3
19	11.742	.337	-5671.8	-3624.5	13.6	-21.3
20	11.726	.468	-8106.2	-4166.8	15.7	-30.5
21	11.705	.599	-10601.4	-4872.2	18.4	-39.9
22	11.679	.729	-13181.9	-5722.5	21.6	-49.6
23	11.648	.858	-15892.0	-6667.3	25.2	-59.8
24	11.612	.986	-18763.5	-7607.8	28.7	-70.6
25	11.493	1.331	-12637.2	-7668.0	28.9	-47.5
26	11.441	1.453	-14873.3	-9920.0	37.4	-55.9
27	11.385	1.573	-17001.6	-11937.7	45.0	-63.9
28	11.323	1.690	-19028.5	-13940.8	52.6	-71.5
29	11.258	1.804	-21012.8	-15924.5	60.1	-78.9
30	11.188	1.916	-23003.1	-18073.8	68.2	-86.4
31	11.113	2.025	-24993.9	-20475.4	77.3	-93.9
32	11.035	2.132	-27033.0	-23110.4	87.2	-101.5
33	10.953	2.235	-29087.8	-26083.0	98.5	-109.2
34	10.866	2.334	-31208.8	-29489.4	111.3	-117.1
35	10.776	2.431	-33517.6	-33301.9	125.7	-125.8
36	10.681	2.524	-36068.6	-37627.8	142.0	-135.3

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END  MDPFRC
025400 MAXIMUM EXECUTION FL.
   .261 CP SECONDS EXECUTION TIME.
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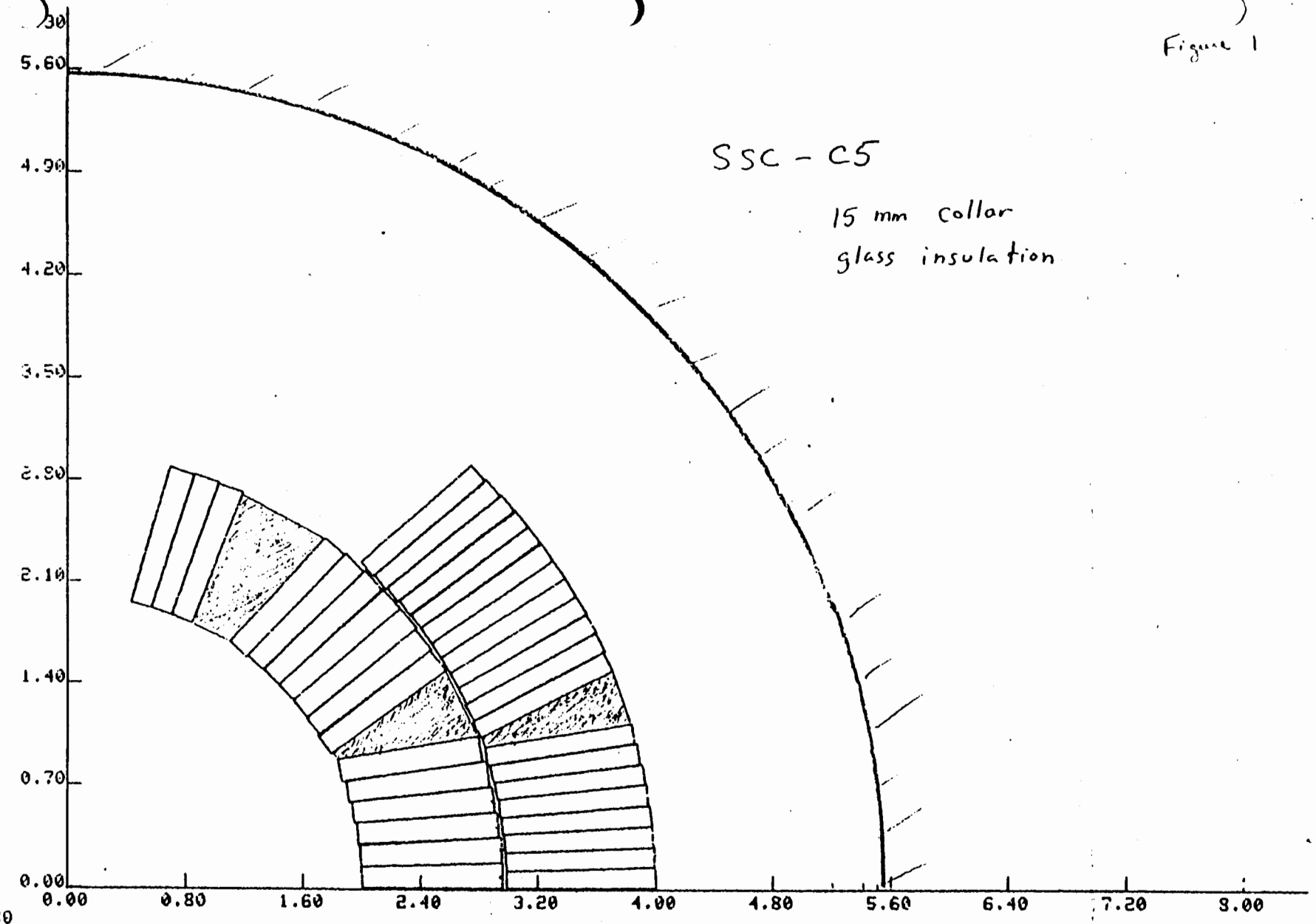
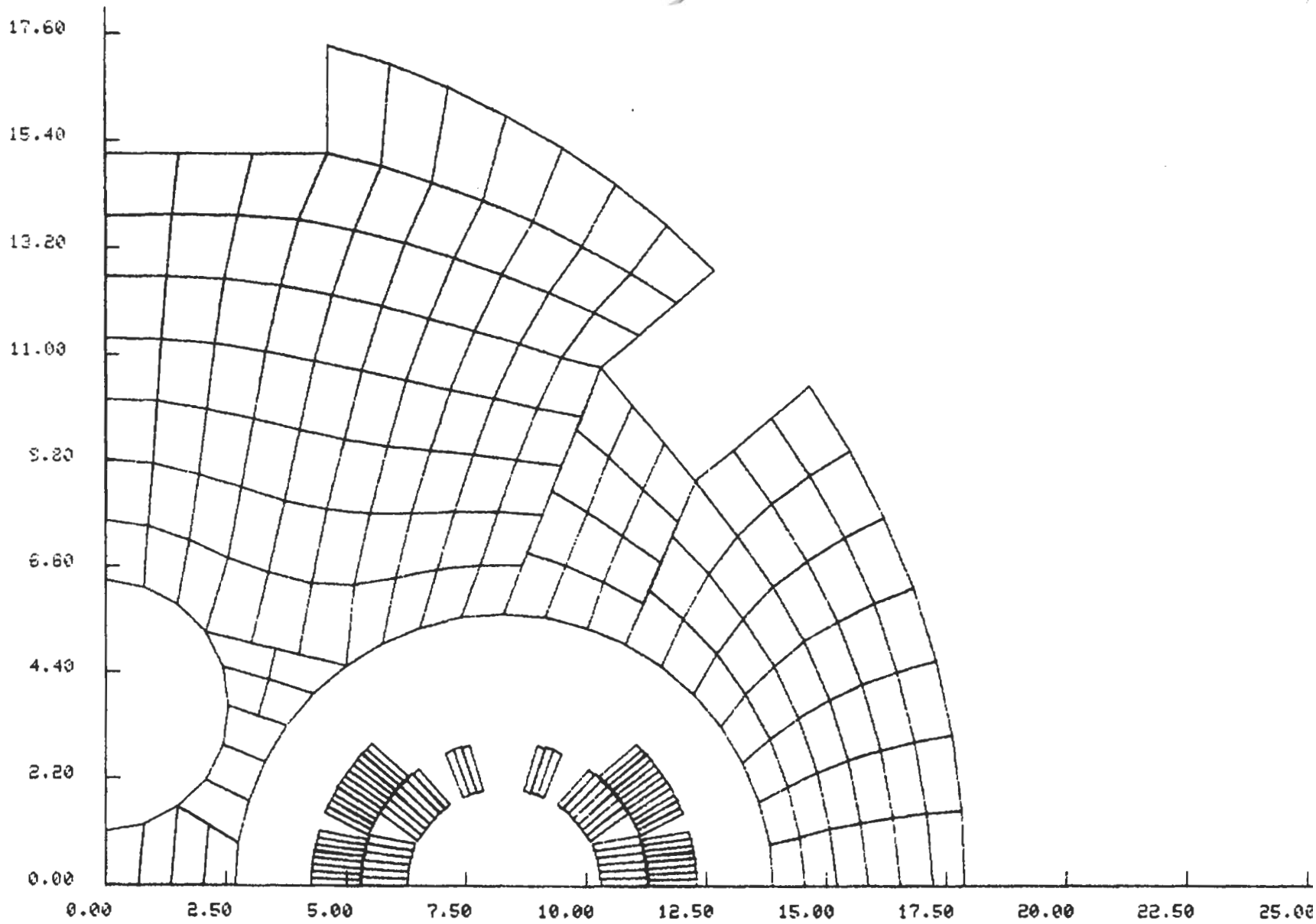
Table 5

Figure 1


SSC - C5
15 mm collar
glass insulation
5.60
4.90
4.20
3.50
2.80
2.10
1.40
0.70
0.00
0.00
0.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40
7.20
8.00

SSC-CS	x_1	y_1	x_2	y_2	x_3	y_3	x_4	y_4	ϕ_1	ϕ_2	ϕ_3	ϕ_4
1	1.9956	.0076	1.9965	.1549	2.9588	.1821	2.9613	.0076	.22	4.44	3.52	.15
2	1.9907	.1548	1.9445	.3020	2.9457	.3563	2.9530	.1819	4.45	8.65	6.90	3.53
3	1.9733	.3013	1.9629	.4483	2.9222	.5297	2.9345	.3556	8.68	12.86	10.27	6.91
4	1.9464	.4469	1.9318	.5935	2.8884	.7020	2.9056	.5283	12.93	17.08	13.66	10.31
5	1.9099	.5910	1.8912	.7371	2.8443	.8726	2.8664	.6995	17.19	21.29	17.05	13.71
6)	1.8658	.7332	1.8410	.8788	2.7900	1.0411	2.8169	.8687	21.47	25.52	20.46	17.14
(6)	2.0202		2.9616									
.1750E+01												
1	1.7924	.9238	1.7034	1.0412	2.4622	1.6335	2.5677	1.4945	27.27	31.43	33.56	30.20
2	1.7140	1.0494	1.6217	1.1643	2.3635	1.7776	2.4728	1.6418	31.48	35.68	36.95	33.58
3	1.6279	1.1694	1.5324	1.2816	2.2566	1.9158	2.3697	1.7829	35.69	39.91	40.33	36.96
4	1.5344	1.2834	1.4358	1.3928	2.1418	2.0472	2.2587	1.9176	39.91	44.13	43.71	40.33
5	1.4338	1.3910	1.3322	1.4976	2.0195	2.1717	2.1399	2.0454	44.13	48.35	47.08	43.71
6	1.3264	1.4920	1.2218	1.5957	1.8898	2.2889	2.0137	2.1661	48.36	52.56	50.46	47.09
7)	1.2125	1.5860	1.1050	1.6867	1.7531	2.3985	1.8805	2.2792	52.60	56.77	53.84	50.48
(14)	2.0051		2.9616									
.9199E+01												
1	.8443	1.8150	.7102	1.8672	1.0319	2.7745	1.1955	2.7139	64.96	69.18	69.50	66.23
2	.7111	1.8697	.5716	1.9170	.8675	2.8330	1.0328	2.7771	69.16	73.40	72.97	69.60
3)	.5707	1.9144	.4299	1.9577	.6999	2.8818	.8567	2.8305	73.40	77.61	76.35	72.98
(3)	1.9997		2.9616									
1	2.9969	.0076	2.9856	.1288	3.9913	.1499	3.9928	.0076	.15	2.47	2.15	.11
2	2.9829	.1287	2.9791	.2498	3.9442	.2920	3.9886	.1498	2.47	4.79	4.19	2.15
3	2.9740	.2496	2.9677	.3706	3.9717	.4338	3.9791	.2918	4.80	7.12	6.23	4.19
4	2.9602	.3701	2.9514	.4910	3.9538	.5752	3.9642	.4333	7.13	9.44	8.28	6.24
5	2.9415	.4901	2.9301	.6108	3.9306	.7160	3.9440	.5744	9.46	11.77	10.32	8.29
6	2.9179	.6096	2.9040	.7298	3.9020	.8560	3.9184	.7147	11.80	14.11	12.37	10.34
7	2.8894	.7280	2.8730	.8480	3.8681	.9951	3.8874	.8541	14.14	16.45	14.43	12.39
8)	2.8560	.8455	2.8370	.9652	3.8289	1.1330	3.8511	.9926	16.49	18.79	16.48	14.45
(8)	2.9870		3.9844									
.1489E+01												
1	2.8056	1.0377	2.7524	1.1450	3.6387	1.6209	3.7046	1.4940	20.28	22.59	24.01	21.98
2	2.7529	1.1507	2.7045	1.2568	3.5806	1.7512	3.6492	1.6268	22.61	24.93	26.06	24.02
3	2.7128	1.2615	2.6522	1.3664	3.5177	1.8790	3.5839	1.7559	24.94	27.26	28.11	26.07
4	2.6583	1.3700	2.5955	1.4736	3.4501	2.0043	3.5239	1.8826	27.27	29.59	30.15	28.11
5	2.5995	1.4761	2.5345	1.5784	3.3778	2.1268	3.4541	2.0068	29.59	31.91	32.20	30.16
6	2.5365	1.5797	2.4694	1.6806	3.3010	2.2465	3.3798	2.1281	31.91	34.24	34.24	32.20
7	2.4694	1.6806	2.4002	1.7800	3.2199	2.3633	3.3010	2.2465	34.24	36.56	36.28	34.24
8	2.3983	1.7796	2.3270	1.8766	3.1342	2.4769	3.2179	2.3619	36.56	38.88	38.32	36.28
9	2.3232	1.8730	2.2498	1.9702	3.0443	2.5873	3.1304	2.4741	38.89	41.21	40.36	38.32
10	2.2442	1.9650	2.1689	2.0607	2.9502	2.6944	3.0386	2.5829	41.22	43.54	42.40	40.37
11	2.1615	2.0547	2.0842	2.1480	2.8521	2.7979	2.9428	2.6883	43.55	45.86	44.45	42.41
12)	2.0751	2.1403	1.9958	2.2320	2.7499	2.8978	2.8429	2.7902	45.89	48.20	46.50	44.46
(12)	2.9870		3.9885									



... 85 LBL09 W/SSC-C5 COILS 9/12/84

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SSC Technical Note No. 19

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R. C. Fernow and G. H. Morgan

March 5, 1985*

* This is an Addendum to SSC Tech Note No. 19

Table 5 which gives the force on the coils is in error; although the magnitude is correct the direction is not. The field of the coils was recomputed with coil current of 6400A. This current gives a central field of 6.5065T and the forces on the coils are given in the revised Table 5.

NO.	X,CM	Y,CM	BX,G	BY,G	FR,LB/IN	FTH,LB/IN
1	10.747	.083	-598.2	-43796.5	159.6	-7.8
2	10.737	.249	-2426.1	-43900.3	158.5	-24.8
3	10.717	.410	-4299.1	-44115.1	156.2	-41.9
4	10.686	.569	-6227.9	-44483.2	152.9	-59.1
5	10.646	.727	-8334.2	-44915.2	148.0	-76.8
6	10.596	.883	-10764.4	-45393.1	141.1	-95.2
7	10.397	1.282	-4692.0	-44919.5	131.9	-98.9
8	10.309	1.417	-6957.8	-47555.3	128.4	-119.4
9	10.212	1.546	-9222.2	-49876.3	122.0	-139.2
10	10.103	1.669	-11473.3	-51951.5	112.8	-158.0
11	9.996	1.786	-13692.4	-53899.3	101.5	-175.7
12	9.872	1.896	-15833.8	-55805.5	88.5	-192.3
13	9.752	1.998	-17892.9	-57928.4	74.5	-208.3
14	9.206	2.306	-9544.9	-51556.6	39.5	-187.2
15	9.055	2.362	-9350.8	-56209.9	33.5	-205.2
16	8.901	2.409	-9030.6	-61249.2	26.1	-224.4
17	11.759	.074	-842.9	-3197.7	11.6	-3.3
18	11.752	.208	-3176.2	-3396.1	11.7	-12.3
19	11.742	.337	-5505.3	-3714.2	11.6	-21.3
20	11.726	.462	-7567.6	-4238.7	11.5	-30.5
21	11.705	.599	-10228.5	-4921.0	11.3	-40.1
22	11.679	.729	-12791.3	-5743.6	10.8	-50.0
23	11.648	.858	-15420.2	-6657.6	9.8	-60.5
24	11.612	.986	-18204.6	-7567.4	7.8	-71.5
25	11.493	1.331	-12261.7	-7620.4	8.7	-52.0
26	11.441	1.453	-14428.5	-9802.7	10.7	-62.7
27	11.385	1.573	-16490.5	-11758.2	11.3	-73.0
28	11.323	1.690	-18453.9	-13699.9	11.3	-83.1
29	11.258	1.804	-20376.0	-15623.2	10.6	-93.1
30	11.188	1.916	-22303.9	-17707.5	9.6	-103.5
31	11.113	2.025	-24232.4	-20037.0	8.5	-114.4
32	11.035	2.132	-26207.9	-22593.2	7.2	-126.1
33	10.953	2.235	-28198.8	-25477.0	6.0	-138.6
34	10.866	2.334	-30254.3	-28781.7	4.7	-152.3
35	10.776	2.431	-32492.3	-32480.5	3.0	-167.6
36	10.681	2.524	-34965.4	-36677.3	.8	-184.9

```
.395 CP SECONDS COMPILATION TIME
END  MDPFRC
025400 MAXIMUM EXECUTION FL.
.287 CP SECONDS EXECUTION TIME.
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