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MAGNETIC FIELD CONSIDERATIONS IN SUPERFERRIC DIPOLE

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Pole Shaping

Iron dominated magnets (Figure 1) are characterized in the limit of inifinite permeability by a pole shape that is a magnetic equipotential where $v = \int H \cdot d\ell$. Deviations from this ideal because of finite permeability are associated with: differences in path length, local saturation, flux concentration in slotted pole (Figure 2) if crenellation is used, and sub surface voids.

For moderate field levels the variation in flux path length throughout the iron lowers the magnetic potential on the iron surface more for the longer paths. As the excitation increases the permeability is lowered in regions of high flux density. Crenellation in this region offers some degree of control over the permeability by concentrating the flux. To a lesser degree sub surface voids can be used to control the reluctance of a flux path. The net result suggests that the shape of the effective air gap can be adjusted to be a magnetic equipotential sensibly equivalent to the ideal pole shape for infinite permeability.

Crenellation

Crenellation describes the cross sectional shape of a slotted pole the magnetic consequences of which are used to control the effective air gap.

Longitudinal crenellation uses two types of laminations. One shape is determined by infinite permeability considerations and the other by the inclusion of path length and local saturation effects. In stacking the magnet a few laminations of the first shape are followed by several laminations of the second shape. This pattern is repeated throughout the magnet length.

Transverse crenellation uses a single lamination in which a set of protrusions toward the median plane is determined by the effective air gap assuming infinite permeability (y_B in what follows). Another set of recesses has its level determined by path length and local saturation effects (y_T in what follows). In practice parameterized shapes y_B and y_T (see Table 1) are used to express these curves. Trial and error adjustments of the parameters are made until a reasonable compromise is obtained.

Since longitudinal crenellation is a 3D calculational problem, whereas transverse crenellation is a 2D problem, only the transverse case is explored at present.

Since a slotted pole is used in crenellation it is necessary to know the ratio of iron in the tip to air in the slot. This may be characterized in a smooth manner by a stacking factor in the region to be crenellated. POISSON was used to determine a stacking factor in the pole shim region that gave a significant improvement in field quality of 30 kG. Starting from STACK = .9 an appreciable change occurred only when STACK was less than .5. It was decided that this smooth approximation to crenellation did not contain enough of the physics to continue but that a reasonable starting point might be a 1÷1 iron to air ratio.

Exploratory calculations were made using LINDA. For accurate estimates at least two mesh units are needed both in the air and in the iron for each crenellation. The best results were obtained using a 1/32 inch mesh size with 3 mesh units of iron and 5 mesh units of air describing the slotted pole. Using NSIKL = 0 and NSIKL = 4 for the low field and high field results the parameters for y_B and y_T were obtained as recorded in Table 1.

Having determined good low field and high field properties POISSON was used to explore intermediate cases. Although the low and high field excitations both give rather good field quality in agreement with LINDA, the intermediate excitations give significantly poorer field quality (Figures 3-4 and Table 2). Possibly the inclusion of more parameters such as variable spacing and tapering could improve the quality for intermediate cases without destroying the low and high field cases.

Two Current Dipole

Since the 30 kG magnet envisaged is closer to being iron dominated than conductor dominated it is possible that a geometrical relocation of conductors can control the field shape as saturation develops.

A suitable quality high field can be obtained using a flat pole with a bevel to make the transition to the coil window. At low excitation the poorer quality field can be significantly improved by reducing the vertical height of the coil Thus by using two separate excitation coils an iron shape can be found that yields good field quality at both high and low excitations. Furthermore, intermediate excitations can also be of good quality by fractionally (f) exciting the second coil with respect to the first.

LINDA was used to determine the iron shape and coil disposition for NSIKL = 0 and NSIKL = 4 that satisfied the good field quality requirement.

For this iron shape and coil disposition POISSON is then employed to determine the fractional excitation that gives acceptable fields. These results are shown in two stages. Figures (5-6) and Table 3 result from inputting the geometrical iron shape and coil disposition determined by LINDA. In this sequence, however, only the first coil is excited in order that one may compare with the next sequence in which the second coil is also excited

The final sequence has the fractional excitation (f) optimally adjusted for each case and varies from f = 0 for the low field case to f = 1 for the high field case. These results are given in Figures (7-8) and Table 4.

In conclusion the results for the transversely crenellated dipole are encouraging but incomplete. However, for the two current dipole an adequate preliminary design is available.

Table 1 Superferric Dipole Parameters

Central field	30 kG
Excitation	75 kA-Turns
Number of Turns (for test magnet only)	40
Conductor Current	1875 A
Conductor Size	.05 in. by .05 in.
Current Density (averaged over matrix)	750 kA/in^2 116.25 kA/cm^2 1162.5 A/mm^2
Short Sample Current*	2350 A
Short Sample Current Density	940 kA/in^2 145.7 kA/cm^2 1457 A/mm^2
Peak Field	
Crenellated	30.9 kG
Two Current	30.8 kG

Parameterization

Crenellated (in.) $y_T = \frac{1}{2} + \frac{6}{17} x_T^2 \quad y_B = \frac{1}{2} - \frac{2.25}{17} x_B^2$

Two Current $I_T = \frac{4}{10} f I_{ToT} \quad I_B = I_{TOT} - I_T$

(I in A-Turns and f is relative density)

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*P.M. Mantsch, private communication

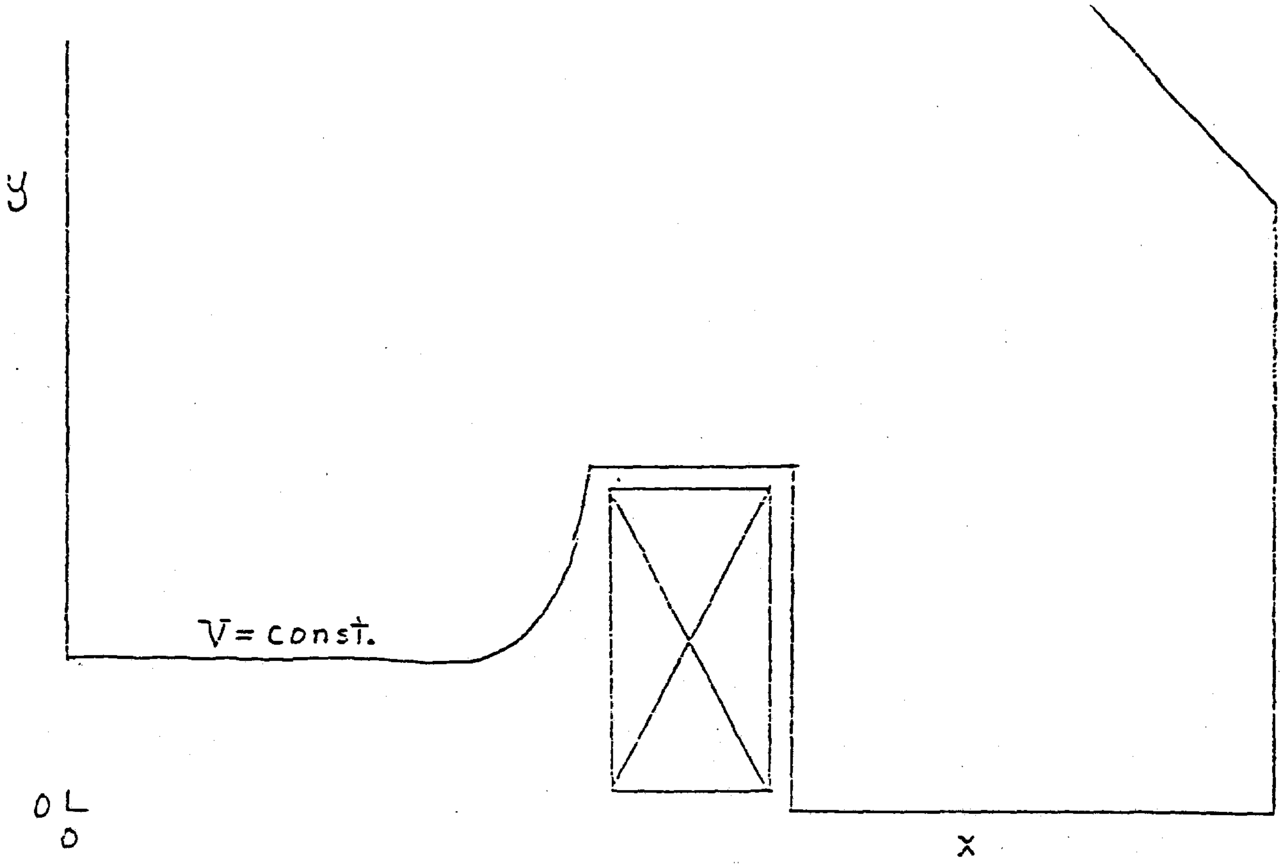


Fig. 1 POLE SHAPING ($\mu = \infty$)

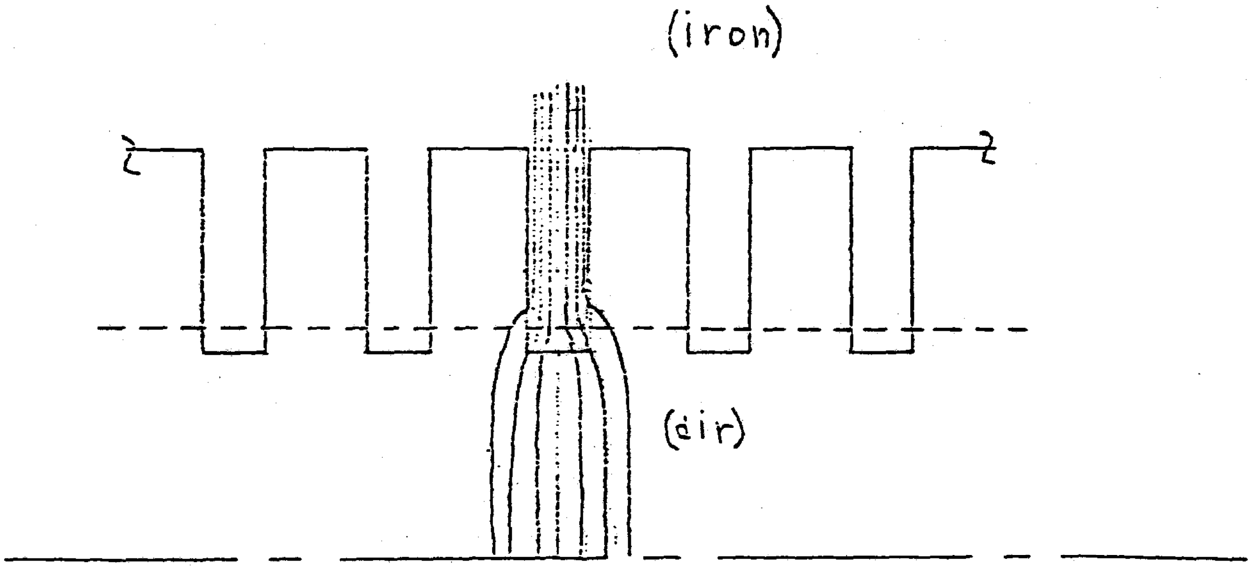
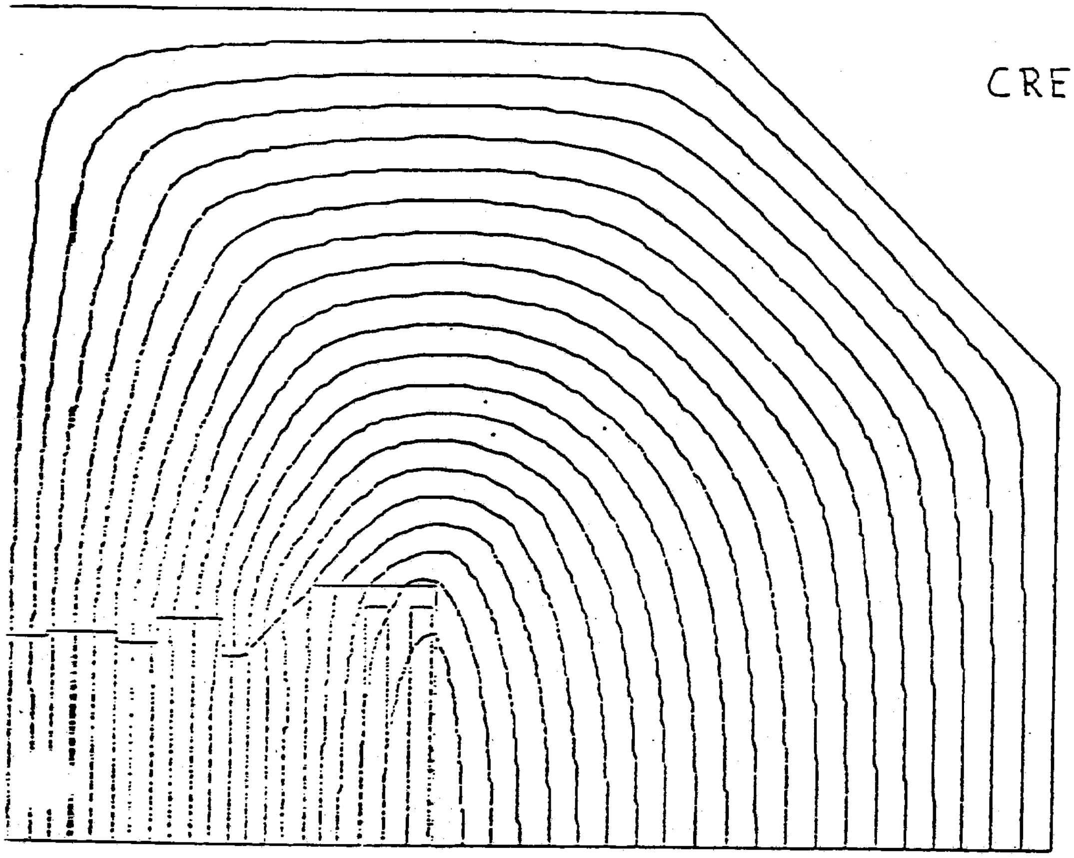


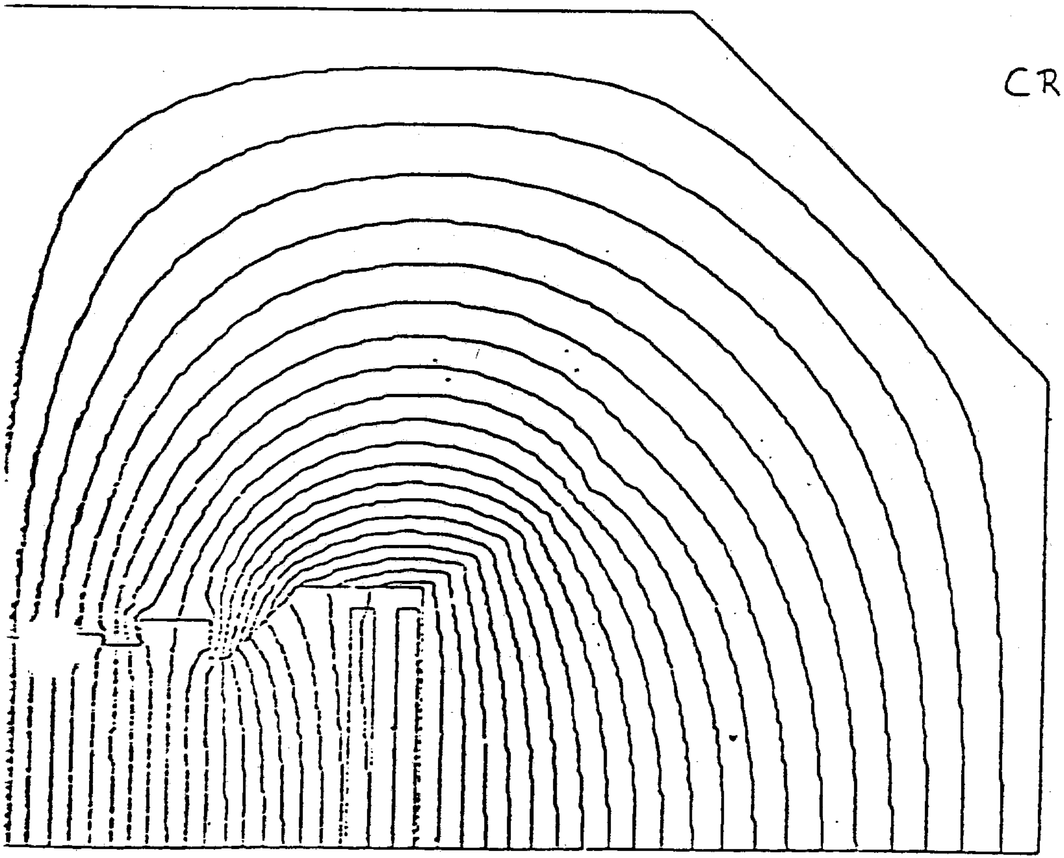
Fig. 2 SLOTTED POLE



CRENELLATED DIPOLE

37602 A
29914 G

Fig. 4



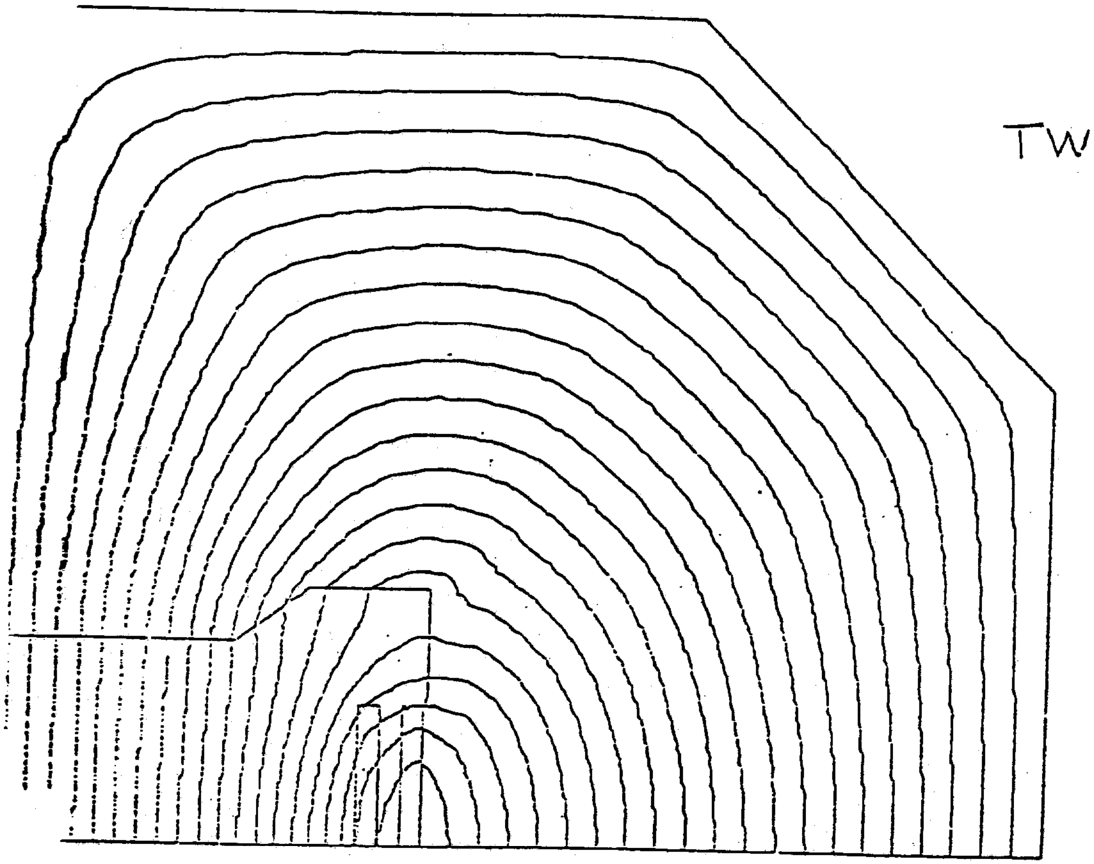
CRENELLATED DIPOLE

2000 A
1972 G

Fig. 3

Table 2. CRENELLATED DIPOLE (TRANSVERSE)

Excitation (A-Turns/pole)		2000	15000	22000	29000	37620
Central Field (G)		1972	14675	20957	25443	29914
Ampfac		1.0000	1.0081	1.0352	1.1241	1.2395
Median Plane Field ($\Delta B/B_o$)						
	x(in)					
	.0000	.000000	.000000	.000000	.000000	.000000
	.0717	.000032	-.000470	-.000718	-.000384	-.000022
	.1178	.000073	-.001278	-.001935	-.001031	-.000052
	.1639	.000088	-.002521	-.003756	-.001991	-.000078
	.2151	-.000023	-.004491	-.006517	-.003427	-.000080
	.2920	-.000801	-.008689	-.011966	-.006205	.000026
Multipole Composition (B_n/B_1 at 0.300")						
	n					
	1	1.000000	1.000000	1.000000	1.000000	1.000000
	3	.000671	-.008208	-.012699	-.006791	-.000405
	5	-.000673	-.000287	.000728	.000668	.000724
	7	-.001266	-.000884	-.000682	-.000495	-.000369
	9	.000586	.000494	.000367	.000268	.000209



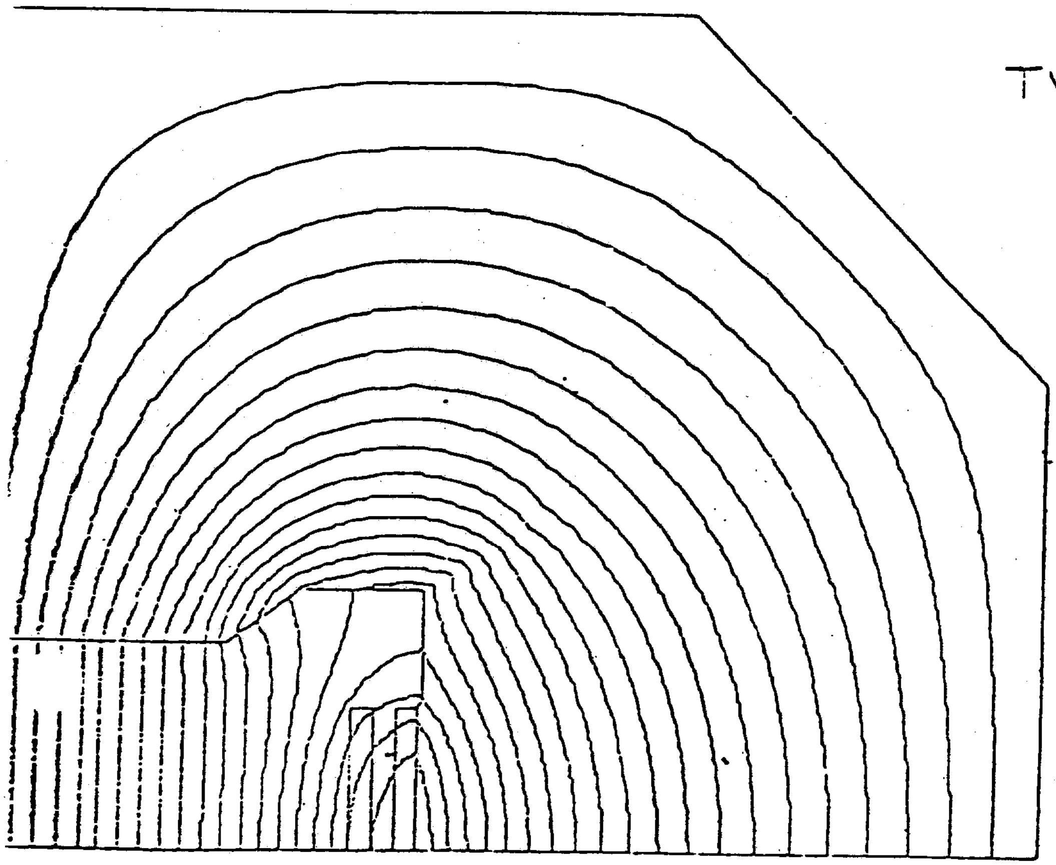
TWO CURRENT DIPOLE
(f=0)

37405 A

0 A

30934 G

Fig. 6



TWO CURRENT DIPOLE
(f=0)

2000 A

0 A

1975 G

Fig. 5

Table 3. TWO CURRENT DIPOLE

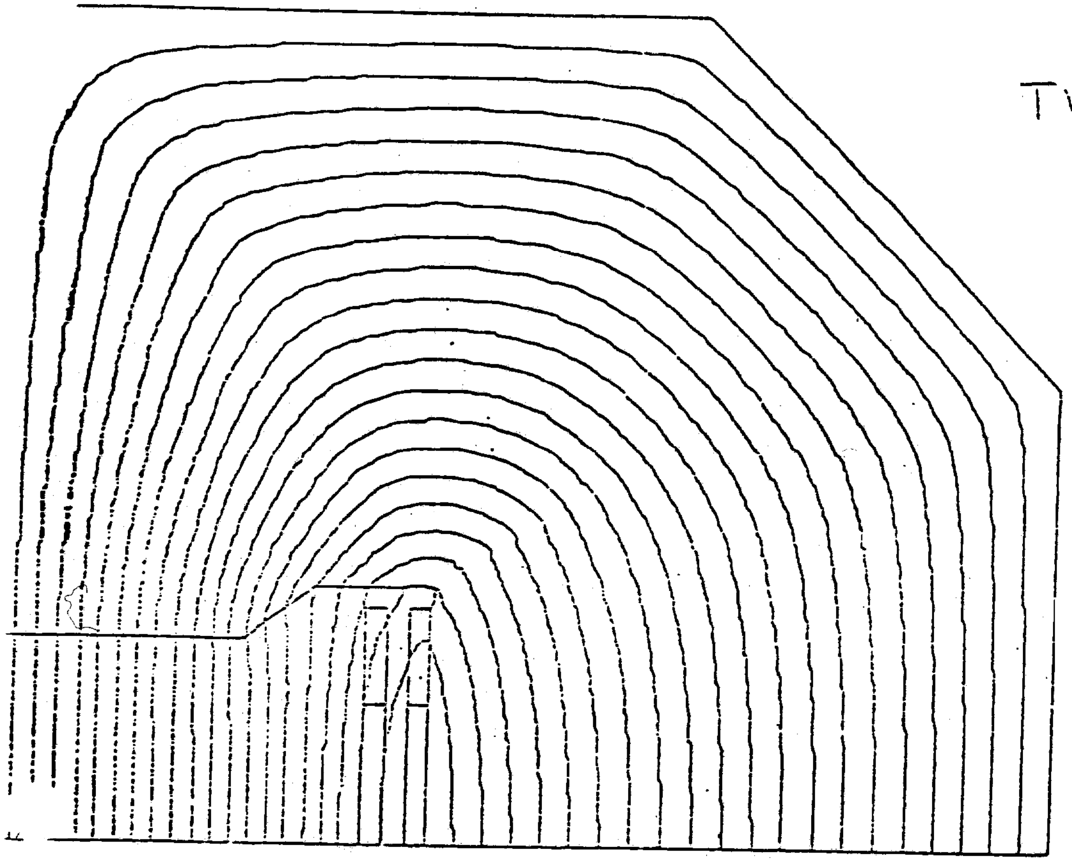
Coil 1 (A-Turns/pole)		2000	15000	22000	29000	37405
Coil 2 (A-Turns/pole)		0	0	0	0	0
Central Field (G)		1975	14826	21459	26237	30934
Ampfac		1.0000	1.0000	1.0124	1.0915	1.1941

Median Plane Field ($\Delta B/B_o$)

x(in)					
.0000	.000000	.000000	.000000	.000000	.000000
.0860	-.000018	-.000023	-.000026	.000451	.001026
.1765	-.000034	-.000059	-.000052	.002008	.004471
.2625	.000115	.000062	.000148	.004886	.010495
.3530	.000960	.000863	.001226	.010260	.020809

Multipole Composition (B_n/B_1 at .300")

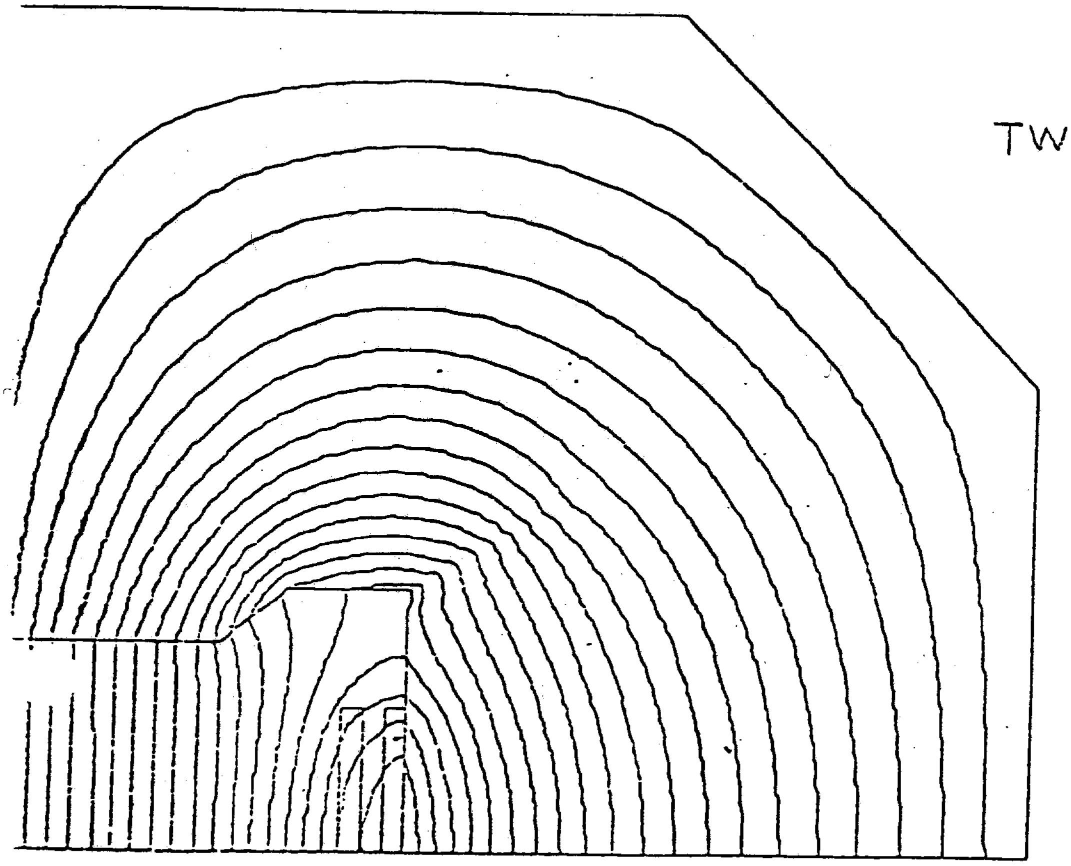
n					
1	1.000000	1.000000	1.000000	1.000000	1.000000
3	-.000270	-.000341	-.000388	-.005392	.012358
5	.000328	.000328	.000527	.001084	.001576
7	.000177	.000178	.000211	.000227	.000233
9	.000007	.000006	-.000002	-.000010	-.000015



TWO CURRENT DIPOLE
(f = 1.0)

22339 A
15066 A
19969 G

Fig. 8



TWO CURRENT DIPOLE
(f = 0)

2000 A
0 A
1977 G

Fig. 7

Table 4. TWO CURRENT DIPOLE

Coil 1 (A-Turns/pole)		2000	14800	21308	22248	22339
Coil 2 (A-Turns/pole		0	120	692	6752	15066
Central Field (G)		1977	14825	21442	25904	29969
Ampfac		1.0000	1.0004	1.0144	1.1069	1.2340
Median Plane Field $(\Delta B/B_o)$						
	x(in)					
	.0000	.000000	.000000	.000000	.000000	.000000
	.0890	-.000014	-.000031	-.000085	-.000053	.000043
	.1513	-.000021	-.000072	-.000227	-.000156	.000105
	.2047	.000013	-.000086	-.000360	-.000283	.000145
	.2581	.000151	-.000016	-.000433	-.000427	.000142
	.3159	.000562	.000293	-.000292	-.000548	.000060
Multipole Composition $(B_n/B_1$ at .300")						
	n					
	1	1.000000	1.000000	1.000000	1.000000	1.000000
	3	-.000196	-.000390	-.001020	-.000616	.000532
	5	.000369	.000327	.000127	-.000079	-.000531
	7	.000183	.000181	.000204	.000129	.000053
	9	.000004	.000005	-.000002	.000001	.000005