APPENDIX III. MAGNET CALCULATIONS

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Optimized parameters for the 45-kG dipole are summarized in Table III-I. The two-shell geometry is shown in Fig. 2 of the main text. Conductor positions are given in Table III-II and magnetic forces in Table III-III. An additional displacement force of 10 lb/in. would be generated if the coil package were displaced from the center of the iron by 0.010 in.

The shell locations given optimize the central-field integral including end effects (3D) as shown in Table III-IV, which also gives the homogeneity of the central field (2D) resulting from this optimization.

The optimized parameters for the 25.7 kG/in. quadrupole are summarized in Table III-V. Note that three shells were required, as shown in Fig. 3 of the main text, to give the required strength using the same conductor and conductor current as in the dipole. Tables III-VI and III-VII contain the conductor locations and magnetic forces in the first octant. An additional displacement force of 11 lb/in. would be generated if the coil package were displaced from the center of the iron by 0.010 in.

The shell locations given optimize the central-field integral including end effects (3D) as shown in Table III-VIII, which also gives the homogeneity of the central field (2D) resulting from the optimization.

Table III-I. Design Data for Dipole Magnet

Central Field	45 kG
Effective Length	252 in.
Conductor Current	4609 A
Total Number of Turns	110
Conductor Size - 23-strand cable (no insulation)	0.304 in. by (0.052/0.050) in.
Effective Current Density	297.3 kA/in.^{2}
Maximum Field at Conductor	49.1 kG
Inner Conductor Radius	1.500 in.
Inner Iron Radius	3.750 in.
Weight of Iron	7375 lb
Weight of Conductor	285 lb
Inductance	0.043 H
Stored Energy	0.51 MJ

Table III-II. Location of Conductor in First Quadrant

Layer	Turns	θ_s (Deg)	θ_f (Deg)	R_0 (in.)	R_1 (in.)	Wrap (in.)	Spacer (in.)
1	34	.1729	72.9489	1.500	1.814	.005	.00093
2	1	.1437	2.0114	1.835	2.153	.007	.00000
3	20	2.0098	37.0405	1.835	2.149	.005	-.00011

Table III-III. Forces on Each Conductor

Layer	Cond.	1	2	3	4	5	6	7	8
1	F_x(lb/in.)	71.2	71.5	71.8	72.3	72.9	73.5	74.3	75.2
		76.1	77.2	78.2	79.4	80.5	81.6	82.5	83.1
		83.3	82.9	82.1	81.4	81.1	81.2	81.8	82.7
		84.1	85.8	87.9	90.4	93.3	96.8	101.0	106.0
		112.3	120.3						
1	F_y(lb/in.)	.4	-1.2	-2.8	-4.4	-6.0	-7.6	-9.3	-11.0
		-12.8	-14.6	-16.5	-18.6	-20.8	-23.1	-25.6	-28.3
		-30.9	-33.4	-34.9	-35.8	-36.1	-36.0	-35.7	-35.2
		-34.5	-33.9	-33.1	-32.3	-31.5	-30.7	-29.8	-29.1
		-28.4	-28.1						
2	F_x(lb/in.)	-11.1	-10.5	-10.2	-9.7	-9.0	-8.1	-7.0	-5.7
		-4.1	-2.4	-.4	1.8	4.3	7.0	10.1	13.5
		17.4	21.8	26.8	32.8	40.1			
2	F_y(lb/in.)	-.4	-3.9	-7.6	-11.3	-14.9	-18.4	-21.9	-25.4
		-28.9	-32.4	-35.9	-39.4	-43.0	-46.5	-50.2	-54.0
		-58.0	-62.3	-67.0	-72.5	-79.1			

Net x-Force on Current in First Quadrant 2953 lb/in.

Net y-Force on Current in First Quadrant -1565 lb/in.

Table III-IV. Field Homogeneity (B_n/B_1 at 1-in. Radius)

	Unsaturated		Finite Permeability	
	(2D)	(3D)	(2D)	(3D)
Dipole	1.00000	1.00000	.99725	.9980
Sextupole	.00119	-.00002	.00130	.0001
Decapole	.00022	.00008	.00032	.0002
14-pole	.00051	.00047	.00014	.0001
18-pole	-.00116	-.00116	-.00054	-.0005
22-pole	.00038	.00037	-.00168	-.0002

Table III-V. Design Data for Quadrupole Magnets

Central Gradient	25.7 kG/in.
Effective Length	53 in.
Conductor Current	4609 A
Total Number of Turns (4-poles)	156
Conductor Size - 23-strand cable (no insulation)	0.304 in. by (0.052/0.050) in.
Effective Current Density	297.3 kA/in.^{2}
Maximum Field at Conductor	46.9 kG
Inner Conductor Radius	1.625 in.
Inner Iron Radius	3.875 in.
Weight of Iron	1330 lb
Weight of Conductor	85 lb
Inductance	0.0065 H
Stored Energy	93 kJ

Table III-VI. Location of Conductors in First Octant

Layer	Turns	θ_s (Deg)	θ_f (Deg)	R_0 (in.)	R_1 (in.)	Wrap (in.)	Spacer (in.)
1	16	1.2861	32.2763	1.625	1.939	.005	-.00081
2	13	1.0826	22.4571	1.960	2.274	.005	-.00027
3	1	.9339	2.4515	2.295	2.613	.007	.00000
4	9	2.4511	15.2720	2.295	2.609	.005	-.00004

Table III-VII. Forces on Each Conductor

Layer	Cond.	1	2	3	4	5	6	7	8
1	F_x(lb/in.)	73.2	73.9	74.5	75.0	75.2	75.4	75.3	75.2
		74.7	74.1	73.1	72.1	71.8	72.5	74.4	77.9
1	F_y(lb/in.)	3.4	-3.7	-10.6	-17.3	-23.8	-30.2	-36.7	-43.0
		-49.3	-55.5	-61.5	-66.8	-71.7	-76.4	-81.8	-88.1
2	F_x(lb/in.)	17.4	17.8	18.2	18.8	19.4	20.0	20.6	21.1
		21.5	22.2	23.8	26.5	30.7			
2	F_y(lb/in.)	2.7	-5.7	-14.0	-22.3	-30.7	-39.2	-47.7	-56.0
		-64.3	-72.0	-79.6	-87.6	-96.7			
3	F_x(lb/in.)	-34.4	-34.0	-33.5	-32.6	-31.1	-29.2	-26.5	-23.1
		-18.9	-13.8						
3	F_y(lb/in.)	1.8	-6.7	-15.2	-23.4	-31.8	-40.3	-49.1	-58.4
		-68.7	-80.4						

Net x-Force on Current in First Octant 1189 lb/in.

Net y-Force on Current in First Octant -1698 lb/in.

Table III-VIII. Field Homogeneity (B_n/B_2 at 1-in. Radius)

	Unsaturated		Finite Permeability	
	(2D)	(3D)	(2D)	(3D)
Quadrupole	1.00000	1.00000	.99995	.9999
12-pole	.00096	.00000	.00096	.0010
20-pole	-.00115	-.00115	-.00115	-.0012
28-pole	.00005	.00005	.00005	.0001