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Summary

Two sizes of narrow quadrupole magnets (8 and 12 in. diam) have been designed and built at Berkeley for use in Bevatron experiments. The quadrupole magnets have a small width for the given aperture, so two or more secondary beams can look at the same target at small production angles. The computer program RNIL[1] was used to develop the pole-tip contour, and the resulting design produced a quadrupole with very small harmonic content. Measurements of the line integral for the 8-in. quadrupole at a gradient of 2800 G/in., measured at a radius of 3.67 in., give harmonic contents, expressed as per cent of second harmonic, of 0.1% for the sixth, ≤0.03% for the tenth, and 0.05% for the fourteenth.

Design Objectives

The design objectives for the narrow quadrupoles were: (1) They should use the same coils as the existing 8QB and 12QB type Berkeley quadrupoles. (2) They should have the same aperture as these existing quadrupoles. (3) They should be as narrow as the existing coils would permit. (4) The pole contour should be redesigned to reduce the excessive 6th harmonic present in the QB type magnets.

Pole-Face Contour Design

The pole-face contours were designed using the computer program RNIL. RNIL is a general, two-dimensional, linear optimization program which assumes infinitely permeable iron. The boundary conditions then imply that lines of flux are everywhere normal to the iron, and symmetry demands that lines of flux be normal to certain planes of symmetry that are specified for each magnet type. The main subroutine of RNIL, named PISA (Program for Inversion of System Analysis) and described in detail in Ref. 1, inverts the forward program to find a set of pole-tip coordinates which minimize the sum of the weighted squares of the deviations between the desired and calculated magnetic fields at various specified points in the aperture.

The 32-in-long, 8-in.-diam (8QN32) and the 24-in.-long, 12-in.-diam (12QN24) narrow quadrupoles have been measured, and the following tables compare the measured and calculated harmonic contents. Table II compares the harmonics of the total line integral for the 8QB32 and the 8QN32 quadrupoles. Table III compares the calculated harmonics, assuming an infinitely long magnet, with the measured harmonics of the line integral over the central 8 in. for the 8QN32 magnet. Table IV compares the measured harmonics of the total line integral, the measured harmonics of the line integral of the central 8 in., and the calculated harmonics, assuming infinitely long iron, for the 12QN24 magnets.

Fabrication

The magnet cores are made up of four identical solid steel slabs which were Blanchard-ground to size and contoured on a shaper. The contour was controlled by matching to a gage produced on a numerical-control mill to a tolerance of ± 0.0005 in. The resulting contour produced by the shaper was within ± 0.002 in. of the desired calculated curve. Table V and Fig. 1 give some of the coordinates used to produce the contours. In making the gage, coordinates were given at about 0.005-in. spacing, and a smooth curve was produced between the points. The utilities are underneath the magnet, leaving the sides and ends as clear as possible to permit close packing. Figure 2 shows the basic dimensions of the magnet.

References

1. Klaus Halbach, A Program for Inversion of System Analysis and Its Application to the Design of Magnets, UCRL-17436; submitted to 2nd International Conference on Magnet Technology, Oxford University, England, July 1967.

Table I
Maximum design values.

	8QN		12QN	
Length (in.)	16	32	24	48
I (A)	2750	2750	2750	2750
V (volts)	53	93	73	126
$\frac{\delta B}{\delta r}$ (kG/in.)	3.6	3.6	2.4	2.4

*Work performed under auspices of U. S. Atomic Energy Commission.

Table II.

Total line integral of magnetic field at r=3.7 in.

	Harmonics in % of second			
	6th	10th	14th	other
8QB $\frac{\delta B}{\delta r}$ = 2500 G/in.	0.35	0.05	0.05	~0.0
8QB $\frac{\delta B}{\delta r}$ = 3000 G/in.	0.36	0.04	0.05	~0.0
8QN $\frac{\delta B}{\delta r}$ = 1400 G/in.	0.07	< 0.02	0.03	< 0.02
8QN $\frac{\delta B}{\delta r}$ = 2800 G/in.	0.10	< 0.03	0.05	< 0.03

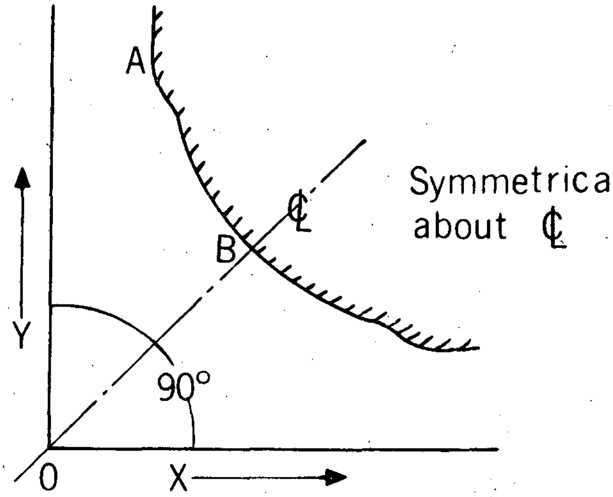

Fig. 1. Contour coordinates.

Table III.

Line integral over central 8 in. of 32 in. quad.

$\frac{\delta B}{\delta r}$ = 3000 G/in. I = 2200 A r = 3.67 in.

	Harmonics in % of second			
	6th	10th	14th	other
8QN (calculated)	0.001	0.0004	~ 0.0	~0.0
8QN32 (measured)	0.008	0.003	0.004	< 0.005

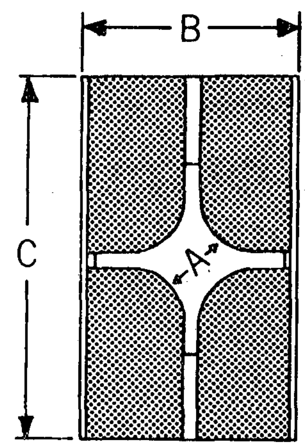

Fig. 2. Basic dimensions (in.)

	8QN	12QN
A	8.244 diam	12.369 diam
B	24.0	35.0
C	40.0	60.0

Table IV.

12QN24 $\frac{\delta B}{\delta r}$ = 2400 G/in. I = 2750 A r = 5.67 in.

	Harmonics in % of second			
	6th	10th	14th	other
12QN24 measured total line integral	0.484	0.019	0.025	<0.015
12QN24 measured line integral of center 8 in.	0.095	0.024	0.009	<0.015
12QN calculated	0.001	0.0004	~ 0.0	~0.0

Table V. Pole-tip contour. x-y Coordinates, Pt. A to B.

8QN				12QN					
x	y	x	y	x	y	x	y	x	y
1.516	5.400	2.047	4.150	2.250	8.175	2.817	6.925	3.444	5.550
1.529	5.275	2.113	4.025	2.258	8.050	2.840	6.800	3.524	5.425
1.582	5.175	2.180	3.900	2.275	7.975	2.862	6.675	3.607	5.300
1.636	5.100	2.250	3.775	2.303	7.900	2.902	6.550	3.694	5.175
1.689	5.025	2.330	3.650	2.360	7.800	2.959	6.425	3.786	5.050
1.762	4.900	2.411	3.525	2.462	7.675	3.028	6.300	3.882	4.925
1.817	4.775	2.500	3.400	2.566	7.550	3.098	6.175	3.983	4.800
1.861	4.650	2.595	3.275	2.652	7.425	3.163	6.050	4.090	4.675
1.893	4.525	2.698	3.150	2.716	7.300	3.229	5.925	4.202	4.550
1.926	4.400	2.810	3.025	2.760	7.175	3.297	5.800	4.320	4.425
1.980	4.275	2.915	2.915	2.790	7.050	3.369	5.675	4.373	4.373

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