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FIELD MEASUREMENTS ON 200-MeV TRANSFER QUADRUPOLES

R. Juhala

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The quadrupoles used in the 200-MeV transfer line have been tested for uniformity of gradient. These magnets are 10-in. long and have a 3.250-in. bore. The internal gradient is approximately 2.0 kG/in. at 45 A. Using the search coil integrator technique, the integrated gradient and uniformity in gradient have been measured. Finally, measurements of the spacing between opposite poles were made. Measurements have been made on two different quadrupoles with some significant differences appearing between them.

Using a long coil which extended 7 in. beyond each end of the quadrupole, the gradient as a function of current was measured by moving the coil between two points across the horizontal aperture. The quantity thus determined is $\int B'dl$. The accuracy of this measurement is limited by the uncertainty in the effective coil width. The error in the gradient is estimated to be between -3.0% and 0.0% (the minimum width of the coil is known to within 0.1% error). For quadrupole # 555 the coil was moved between x = ±1.0 in. and for quadrupole # 545 the two points were ±0.5 in. These results are given in Table I below. The current is accurate to ±0.25%.

Table I. Field Gradient in the 200-MeV Transfer Quadrupoles.

Current (A)	$\int B'dl$ (kG)	
	Magnet # 545	Magnet # 555
5.14		2.475
5.13	2.26	
10.13		5.00
10.13	5.15	
15.15		7.55
15.27	7.77	
20.24		10.17
20.30	10.33	
25.08		12.61
25.17	12.79	
30.48		15.36
30.14	15.29	
35.22		17.69
35.20	17.82	
40.15		20.21
40.00	20.19	
45.41		22.81
45.15	22.74	
50.30		25.14
50.06	25.12	

The uniformity of the gradient was determined by two different measurements. The first employed a pair of 2-in. long coils bucked against each other. The second measurement used a pair of coils that are 24-in. long and extended beyond each end of the magnet. Using them the uniformity was measured in the horizontal plane between x = ±1.4 in. at currents of 30 and 40 A. There was no significant change in the uniformity between these two currents so only the results for 40 A are given in Table II. The quantity determined is $\Delta G/G = \left[\int B'(x)\,dz - \int B'(o)\,dz\right] / \int B'(o)\,dz$ integrated either along the 2-in. coils (does not include end effects) or along the 24-in. coils (which includes end effects).

Table II. Gradient Uniformity for 200-MeV Transfer Quadrupoles.

x (in.)		ΔG/G%	
	#545 (2-in. coils)	(24-in. coils)	#555 (24-in. coils)
1.4	-2.46	-4.31	-3.54
1.2	-0.51	-1.58	-0.94
1.0	+0.08	-0.45	-0.37
0.8	+0.18	-0.04	-0.08
0.6	+0.15	+0.08	-0.01
0.4	+0.09	+0.08	-0.01
0.2	+0.04	+0.05	-0.01
0.0	0.0	0.0	0.0
-0.2	-0.06	-0.05	+0.03
-0.4	-0.11	-0.12	+0.08
-0.6	-0.17	-0.22	+0.12
-0.8	-0.25	-0.42	+0.10
-1.0	-0.43	-0.85	-0.12
-1.2	-0.98	-1.84	-0.92
-1.4	-2.44	-4.08	-3.02

It is noted that there is a difference in the uniformity between the two magnets as determined from the 24-in. coil data. This is probably due to the differences in pole spacing of the two magnets. Numbering the poles from 1 to 4 in a clockwise direction one has 1 and 3, together with 2 and 4 as poles diametrically opposite each other. The distance between these opposite poles was measured at each end of the magnet. The results are as follows:

a) Magnet #545	lead end	1-3	3.255 in.
		2-4	3.250 in.
	far end	1-3	3.245 in.
		2-4	3.251 in.

b) Magnet # 555	lead end	1-3	3.255 in.
		2-4	3.255 in.
	far end	1-3	3.253 in.
		2-4	3.253 in.

Thus one might expect that # 555 having more nearly 4-pole symmetry would have the more uniform field as is borne out by the field measurement data in Table II.

Finally, the d. c. resistances and series inductances have been measured using commercial impedance bridges. These results are given in Table III.

Table III. Resistance and Inductance of the 200-MeV Transfer Quadrupoles.

Magnet #	d. c. Resistance (Ω)	Series Inductance at 1 kHz
545	0.594	1.81mh Q = 1.21
555	0.601	1.85mh Q = 1.29

The measurements on these two quadrupoles indicate that in the best case the gradient is uniform to within ±0.1% over 50% of the aperture. Mechanical measurements of the pole spacing indicate substantial variation is present in the construction of these quadrupoles. Even though a correction to the excitation data (gradient vs current) for Magnet # 555 was made to account for the drop in field gradient of 0.5% at x = ±1.0 in., it appears as though the field gradient in Magnet # 545 is slightly higher at a given current. This difference could be due to inaccuracies in calibration or in variations in the horizontal movement of the positioning device. Nevertheless, these differences are within the range of uncertainty in this data due to an unknown coil width (3%).

Equipment List

1. Hewlet Packard Power Supply NAL # 1012 (current regulation not working).

2. 200-MeV transfer quadrupoles # 545, # 555.

3. 24-in. long coil, 140 turns # 40 wire wound on glass form 0.2346-in. wide, R = 2080.5Ω.

4. 2-in. gradient coils designated L. C. 1 and 2.

5. 24-in. gradient coils.

6. H.P. 2401C integrating digital voltmeter # 901700A.

7. Magnetic Measurements Integrator # 1 c = 1μF R integrator = 6028.2Ω.