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Aperture Dependence Of RHIC Cells On Multipole Fields In The Dedicated RHIC Dipoles

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Abstract: Effects of multipoles in the dedicated RHIC dipoles have been studied by tracking particles through a lattice consisting of 81 RHIC cells. The dynamic aperture with no magnetic multipoles is greater than 59 mm at $\Delta P/P=0$. Inclusion of magnet multipoles reduces the dynamic aperture to ~29 mm. When a 30 mm aperture test is used, the beam size in the dipoles is limited to ~27 mm.

A lattice consisting of 81 RHIC cells (~2π bend) has been used to evaluate the effects of systematic multipoles in the "dedicated" RHIC dipoles. A half cell is 14.80 m long and contains one 10.7 m dipole centered between the quadrupoles; the length of which are 1.9 m. A chromaticity correcting sextupole and a multipole element (SF and MF or SD and MD) are located at the center of each quadrupole, while dipoles have a multipole element MB at each end: Fig. 1.

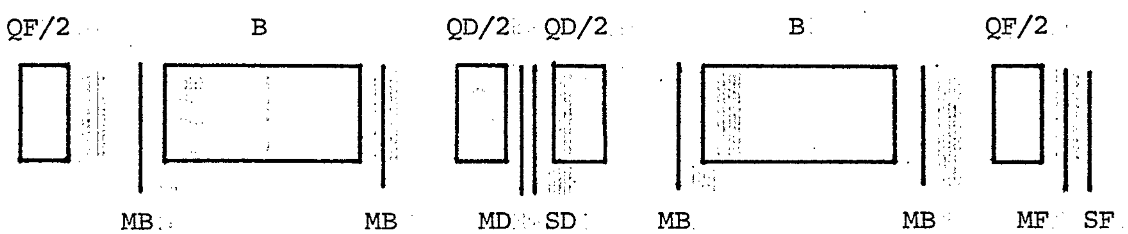


Fig. 1 RHIC Cell

In this study there were no multipole fields associated with the quadrupoles. The dipole multipole coefficients b_n' were obtained from Pat Thompson[1] and are listed in Table I. They are ideal coefficients based on infinite permeability iron and do not include construction errors. The coefficients b_n' represent the field at 2.50 cm and are related to the traditional coefficients b_n by the relation:

$$b_n = b_n'/(2.5)^n .$$

n	$b'_n (10^{-4})$	$b_n (cm^{-n})$	$b_n (m^{-n})$
2	-0.02	-3.20E-07	-3.20E-03
4	-0.01	-2.56E-08	-2.56E+00
6	0.00	0.00	0.00
8	0.04	2.62E-09	2.62E+07
10	0.08	8.39E-10	8.39E+10
12	-0.21	-3.52E-10	-3.52E+14
14	-0.84	-2.26E-10	-2.26E+18
16	0.15	6.44E-12	6.44E+20
18	0.26	1.79E-12	1.79E+24

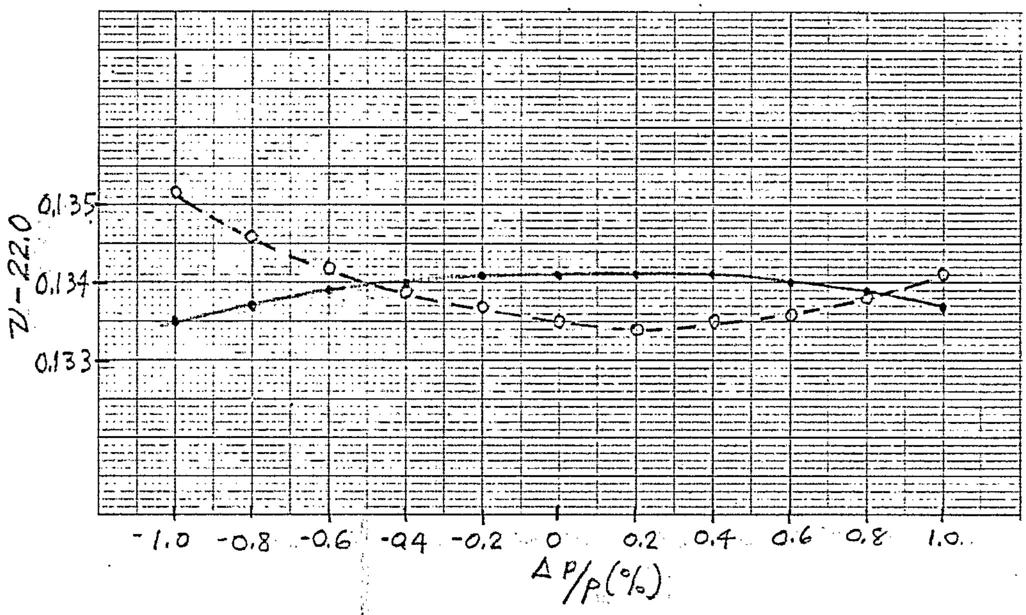
Table I. Systematic multipole coefficients for the RHIC dedicated dipoles.

Tracking runs, with and without multipoles, were made using aperture tests of 1000 mm (dynamic aperture) and 30 mm (physical aperture). The tests were made at every sextupole and multipole element- at the center of the quadrupoles and at both ends of the dipoles.

The emittances in the x and y directions were set equal and were $\epsilon_x = \epsilon_y = N^2\epsilon_0$ with $\epsilon_0 = 0.005$ and with N being the particle amplitude in PATRICIA units. For N=1, $\epsilon_x = \epsilon_y = \epsilon_0$ corresponds to a distance $\Delta r = (\Delta x^2 + \Delta y^2)^{1/2} = (\epsilon_0 (\beta_x + \beta_y))^{1/2}$; Δr is greatest at the quadrupole centers where $\beta_x^F = \beta_y^D = 52.0$ m and $\beta_y^F = \beta_x^D = 7.35$ m. At these positions $\Delta r = 0.545$ mm. Similarly, at the ends of the dipoles $(\beta_x + \beta_y) \sim 52.7$ m and $\Delta r = 0.513$ mm. Each unit change of the PATRICIA amplitude N corresponds to a radial change of the particle's amplitude of 0.545 mm at a quadrupole and 0.513 mm at either end of a dipole.

Throughout the following studies the chromaticity was set to zero in both the x and y planes. The resultant dependence of tune upon momentum is shown in Fig. 2.

The results of runs made with the 1000 mm aperture test and no multipoles are listed in Table II. (In Tables II to VII the quantity N(TURNS) denotes the PATRICIA amplitude N and the number of turns (TURNS) the particle survived at that amplitude. In addition, two entries appear in the column A(mm). The entries under Q and B denote the beam size at the center of the quadrupoles and at the ends of the dipoles, respectively.) Particle trajectories were stable well beyond the magnet aperture of 30 mm, so it was not deemed necessary to determine the actual dynamic aperture.



Fig

Fig. 2 Tune vs momentum (no multipoles)

ΔP/P(%)	N(TURNS)	A(mm) Q	B
0.2	> 80(100)	>43.6	>41.0
0.0	>115(100)	>62.6	>59.0
-0.2	>80(100)	>43.6	>41.0

Table II. Dynamic aperture - no multipoles.

When the magnet multipoles listed in Table I were included, the dynamic aperture was reduced. Even though a particle passed the 1000 mm aperture test at one multipole element, failure was associated with amplitudes of 10^4 to 10^{16} mm at the next multipole element only a few meters away. The results of this study appear in Table III.

ΔP/P (%)	N (TURNS)	A (mm) Q	A (mm) B
0.2	52(100), 54(4)	$28.3 \le A < 29.4$	$26.7 \le A < 27.7$
0.0	56(100), 58(6)	$30.5 \le A < 31.6$	$28.7 \le A < 29.7$
-0.2	52(100), 54(69)	$28.3 \le A < 29.4$	$26.7 \le A < 27.7$

Table III. Dynamic aperture with all multipoles

An effort was made to identify which, if any, multipole played a dominant role in the aperture limitation. A series of runs was made for which one multipole coefficient was set to zero. The column headed "without" indicates which multipole was removed. There seems to be little indication of a "most important" multipole term. These results are listed in Table IV.

Without	N (TURNS)	A (mm) Q	A (mm) B
b_2	54(100), 56(90)	$29.4 \le A < 30.5$	$27.7 \le A < 28.7$
b_4	56(100), 58(6)	$30.5 \le A < 31.6$	$28.7 \le A < 29.7$
b_8	56(100), 58(7)	$30.5 \le A < 31.6$	$28.7 \le A < 29.7$
b_{10}	56(100), 58(7)	$30.5 \le A < 31.6$	$28.7 \le A < 29.7$
b_{12}	54(100), 56(30)	$29.4 \le A < 30.5$	$27.7 \le A < 28.7$
b_{14}	56(100), 58(17)	$30.5 \le A < 31.6$	$28.7 \le A < 29.7$
b_{16}	54(100), 56(67)	$29.4 \le A < 30.5$	$27.7 \le A < 28.7$
b_{18}	54(100), 56(23)	$29.4 \le A < 30.5$	$27.7 \le A < 28.7$

Table IV. Dependence of dynamic aperture upon one missing multipole.

Next, runs were made when half the multipole coefficients were removed; thus b_2 to b_{10} or b_{12} to b_{18} were set equal to zero. These results are listed in Table V. It is seen that removal of b_2 to b_{10} has little effect while removal of b_{12} to b_{18} increased the dynamic aperture by ~ 1 mm.

Without	N(TURNS)	A(mm)	
		Q	B
b_2-b_{10}	54(100),56(4)	$29.4 \leq A \angle 30.5$	$27.7 \leq A \angle 28.7$
b_{12}-b_{18}	76(100),78(54)	$41.4 \leq A \angle 42.5$	$39.0 \leq A \angle 40.0$

Table V. Dynamic aperture at $\Delta P/P = 0$ with half the multipoles removed.

Further runs were made for which (b_{12} and b_{18}), (b_{14} and b_{18}), and (b_{16} and b_{18}) were removed as well as for which (b_{12} and b_{14}) and (b_{14} and b_{16}) were removed. These results are summarized in Table VI. With the exception of the combination (b_{14} and b_{18}) which increased the aperture by $\sim$4 mm, no other combination produced much of an effect.

Without	N(TURNS)	A(mm)	
		Q	B
b_{12}, b_{18}	56(100),58(4)	$30.5 \leq A \angle 31.6$	$28.7 \leq A \angle 29.7$
b_{14}, b_{18}	64(100),66(8)	$34.9 \leq A \angle 36.0$	$32.8 \leq A \angle 33.8$
b_{16}, b_{18}	52(100),54(19)	$28.3 \leq A \angle 29.4$	$26.7 \leq A \angle 27.7$
b_{12}, b_{14}	52(100),54(75)	$28.3 \leq A \angle 29.4$	$26.7 \leq A \angle 27.7$
b_{14}, b_{16}	54(100),56(20)	$29.4 \leq A \angle 30.5$	$27.7 \leq A \angle 28.7$

Table VI. Dependence of dynamic aperture at $\Delta P/P = 0$ upon removal of pairs of multipoles.

Finally, runs were made using a 30 mm aperture test in both the quadrupoles and dipoles. The results for four different conditions: 1). No multipoles, 2). All multipoles, 3). b_2 to b_{10}, and 4). b_{12} to b_{18} are listed in Table VII.

	N(TURNS)	A(mm)	
		Q	B
No Multipoles	52(100),54(1)	$28.3 \leq A < 29.4$	$26.7 \leq A < 27.7$
All Multipoles	52(100),54(1)	$28.3 \leq A < 29.4$	$26.7 \leq A < 27.7$
b_2 -b_{10}	52(100),54(1)	$28.3 \leq A < 29.4$	$26.7 \leq A < 27.7$
b_{12}-b_{18}	52(100),54(1)	$28.3 \leq A < 29.4$	$26.7 \leq A < 27.7$

Table VII. Physical aperture (30 mm test) at $\Delta P/P = 0$.

At the 100 turn level, the physical aperture is independent of whether or not multipoles are included. However, the dynamic aperture from Table III is only 2 mm larger than the physical aperture listed in Table VII that was determined by beam size in the quadrupoles.

Summary

The dynamic aperture without magnet multipoles wasn't fully determined but was found to be larger than 59 mm in the dipoles at $\Delta P/P = 0.0$. When all systematic multipoles were included, the dynamic aperture in the dipoles was reduced to $28.7 \leq A < 29.7$ mm. Removal of individual multipoles had little effect on the dynamic aperture; removal of b_{12} to b_{18} increased the dynamic aperture by $\sim$11 mm, indicating that the higher order fields play a significant role in determining the aperture. Removal of b_{14} & b_{18}, only, increased the aperture by $\sim$4 mm.

Finally, the physical aperture, determined by a 30 mm test in the dipoles and quadrupoles, was $26.7 \leq A < 27.7$ in the dipoles both with and without multipoles. This aperture is determined by beam size in the quadrupoles. Even so, the corresponding beam size in the dipoles is within 1 to 2 mm of the dynamic aperture of the dipoles. In the event that multipole coefficients for "real" dipoles are larger than those in Table I, the dynamic aperture rather than the physical aperture could be the limiting aperture.

References

1. Pat Thompson, Private communication; information derived from Magnet Note 33-16, Jan. 12, (1984).