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Acceptance of ß* =2m, 3m, and 6m Lattices With Reduced Aperture BC1(17 cm) and BC2(8 cm) Dipoles

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A determination of the physical aperture has been made by particle tracking on three RHIC lattices having β^* = 2m, 3m, and 6m when dipoles BC1 and BC2 have coil i.d.'s that are reduced from 20 to 17 cm and 10 to 8 cm, respectively. The magnet multipoles in these dipoles have been scaled as $b_n(r_2)=b_n(r_1)(r_1/r_2)^{n+0.5}$, where r_1 is the original coil i.d., and r_2 is the new coil i.d. Random multipoles are generated according to a gaussian distribution that is truncated at $\pm 3\sigma$. No systematic multipoles are included, and $a_1=b_1=0$.

The three lattices have their chromaticity corrected to zero with six families of sextupoles "connected to four power supplies." Using SF_o and SD_o to denote the sextupole strengths required to correct the chromaticity to zero with two families of sextupoles, the strengths of alternate SF sextupoles in the inner arcs are set at $\pm\Delta SF$ with respect to SF_o, and the strengths of alternate SD sextupoles in the outer arcs are set at $\pm\Delta SD$ with respect to SD_o.

The aperture determinations have been made at the design tunes of the three lattices; these tunes, natural chromaticities, and values of SF_o, SD_o, ΔSF, and ΔSD are listed in Table 1.

The physical aperture is determined by testing the x and y positions of the test particle at every sextupole, at the center of every quadrupole, and at both ends of every dipole to see if the particle motion has exceeded the inner radius of the vacuum chamber. As usual, a chamber i.d. 8 mm less than the coil i.d. is used. The aperture determination has been made for a crossing angle of 3.4 mradians between the two beams; hence the closed orbit is displaced at both the entrance and exit of the BC1 dipoles. This displacement is shown in Figure 1.

The kick asscociated with magnet multipoles of BC1 includes the effect of the displaced closed orbit ΔX_{co}. Hence:

$$x' = \ell/\rho \; \Sigma b_n(\Delta X_{co}+X_\beta)^n \qquad , \text{ where } x_\beta$$

is the betatron amplitude, and ΔX_{co} is 17 mm at the edge nearest the crossing point and is 52.6 mm at the edge away from the crossing point. The displaced closed orbit is also included when the test is made to determine whether the particle has exceeded the inner dimensions of the vacuum chamber.

The physical aperture has been determined for RHIC lattices having β^* = 2m, 3m, or 6m at all crossing points. The determinations for each lattice have been made for five different random multipole distributions (random number seeds) at three different momentum deviations -- $\Delta P/P$= 0 and $\pm 0.5\%$. Initially the emittance $\varepsilon_x=\varepsilon_y=\varepsilon_o$, and $x'=y'=0$. The initial emittances are changed in steps corresponding to Δx=0.36 mm at a QF quadrupole until the edge of the aperture is found -- the requirement used is that the particle does not survive throughout a 400 turn run with amplitude X_o, but it does survive at amplitudes X_o-0.36, X_o-0.72, and X_o-1.08 mm.

The amplitude X_o-0.18 mm is used as the maximum initial x amplitude that can pass through the vacuum pipe. This x amplitude is then converted to physical aperture by assuming that emittance transfer between the x and y motion is complete -- hence, the physical aperture is : $A_p=\sqrt{2}*(X_o-0.18)$ mm. The average A_p and the values of A_p for each random distribution are tabulated in Table 2 and are plotted on Figure 2.

The assumption of total emittance transfer is substantiated by the tracking results, however the assumption of total emittance transfer back and forth between the two planes is frequently not substantiated. Frequently the direction of emittance transfer is momentum dependent; at one $\Delta P/P$ all emittance will be transferred to the x plane only, and at the other $\Delta P/P$ it will be transferred to the y plane only -- in other cases total emittance transfer will take place to both planes. Hence the use of initial amplitudes to determine apertures can give results that need interpretation.

Of prime interest is the finding that, although tests are made in BC1 on the motion of the particle around the displaced closed orbit, BC1 is not the limiting aperture -- all particles are lost in BC2! Hence, BC2 with its 8 cm coil i.d. is the element that limits the acceptance of RHIC -- this limited acceptance does satisfy the requirements originally specified for β^* = 3m and 6m operation[1], however, in view of changes in rf voltage, emittance growth due to space charge and intrabeam scattering, and the use of β^* = 2m, the requirements should be reviewed.

1. H. Hahn, AD/RHIC-22, 3/2/87.

	β^* = 2m	β^* = 3m	β^* = 6m
ν_x	28.823821	28.825994	28.829418
ν_y	28.822547	28.823003	28.823671
ξ_x	-72.757	-56.974	-45.376
ξ_y	-73.022	-57.012	-45.356
SF_o	-0.209021	-0.163876	-0.130255
SD_o	0.415199	0.324508	0.258078
$\lvert\Delta SF\rvert$	0.07537	0.0275	0.0
$\lvert\Delta SD\rvert$	0.1470	0.0550	0.0

Table 1 Tunes, natural chromaticity, sextupole strength, $|\Delta SF|$, and $|\Delta SD|$ for the β^* = 2m, 3m, and 6m RHIC lattices.

A_p(mm) at $\beta^* = 2m$

RN \ ΔP/P(%)	-0.5	0.0	0.5
1	11.9	11.4	8.2
2	10.8	11.4	11.9
3	11.3	12.4	11.9
4	13.4	12.5	11.9
5	13.0	11.3	8.2
Av	12.1±1.1	11.8±0.6	10.4±2.0

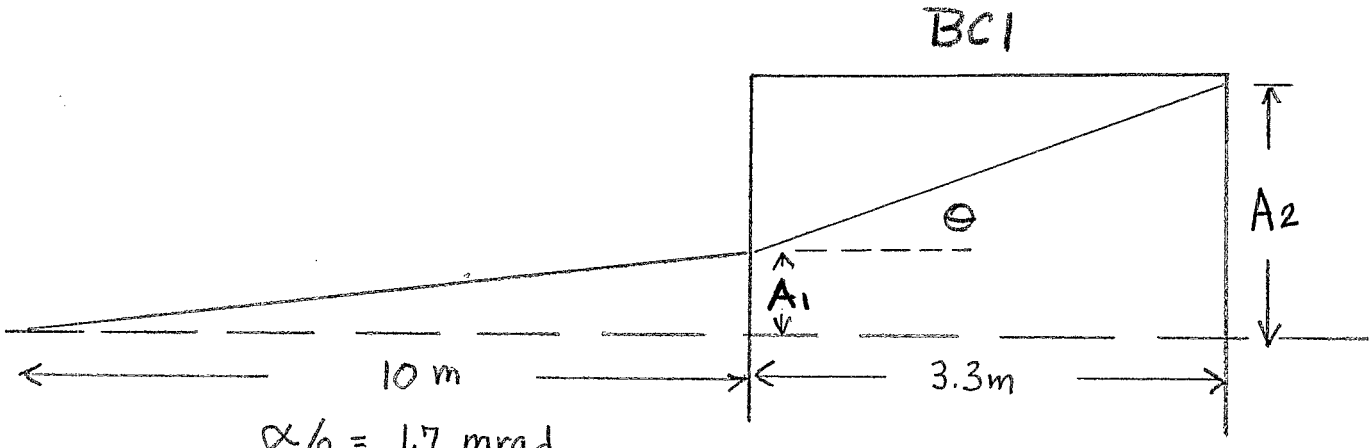
A_p(mm) at $\beta^* = 3m$

RN \ ΔP/P(%)	-0.5	0.0	0.5
1	16.7	16.1	14.0
2	13.0	18.2	17.3
3	15.6	15.6	16.7
4	17.7	16.7	16.1
5	17.7	17.3	17.3
Av	16.1±2.0	16.8±1.0	16.3±1.4

A_p(mm) at $\beta^* = 6m$

RN \ ΔP/P(%)	-0.5	0.0	0.5
1	19.8	24.0	23.6
2	21.5	24.6	24.0
3	19.8	24.0	25.2
4	25.2	24.6	25.2
5	18.2	20.4	21.9
Av	20.9±2.7	23.5±1.8	24.0±1.4

Table 2 Physical aperture determination for five random seeds and the resulting average aperture.



$\alpha/2 = 1.7$ mrad

$\theta_B(BC1) = 18.169$ mrad

$\theta = \alpha/2 + \theta_B/2 = 10.78$ mrad

$A_1 = 10 * 10^3 \tan(1.7 \cdot 10^{-3}) = 17$ mm

$A_2 = A_1 + 3.3 * 10^3 \tan(10.78 \cdot 10^{-3}) = 52.6$ mm

Figure 1 Geometry showing displacement of the closed orbit at BC1 for a 3.4 mradian crossing angle between the two RHIC beam. Equal species were assumed.

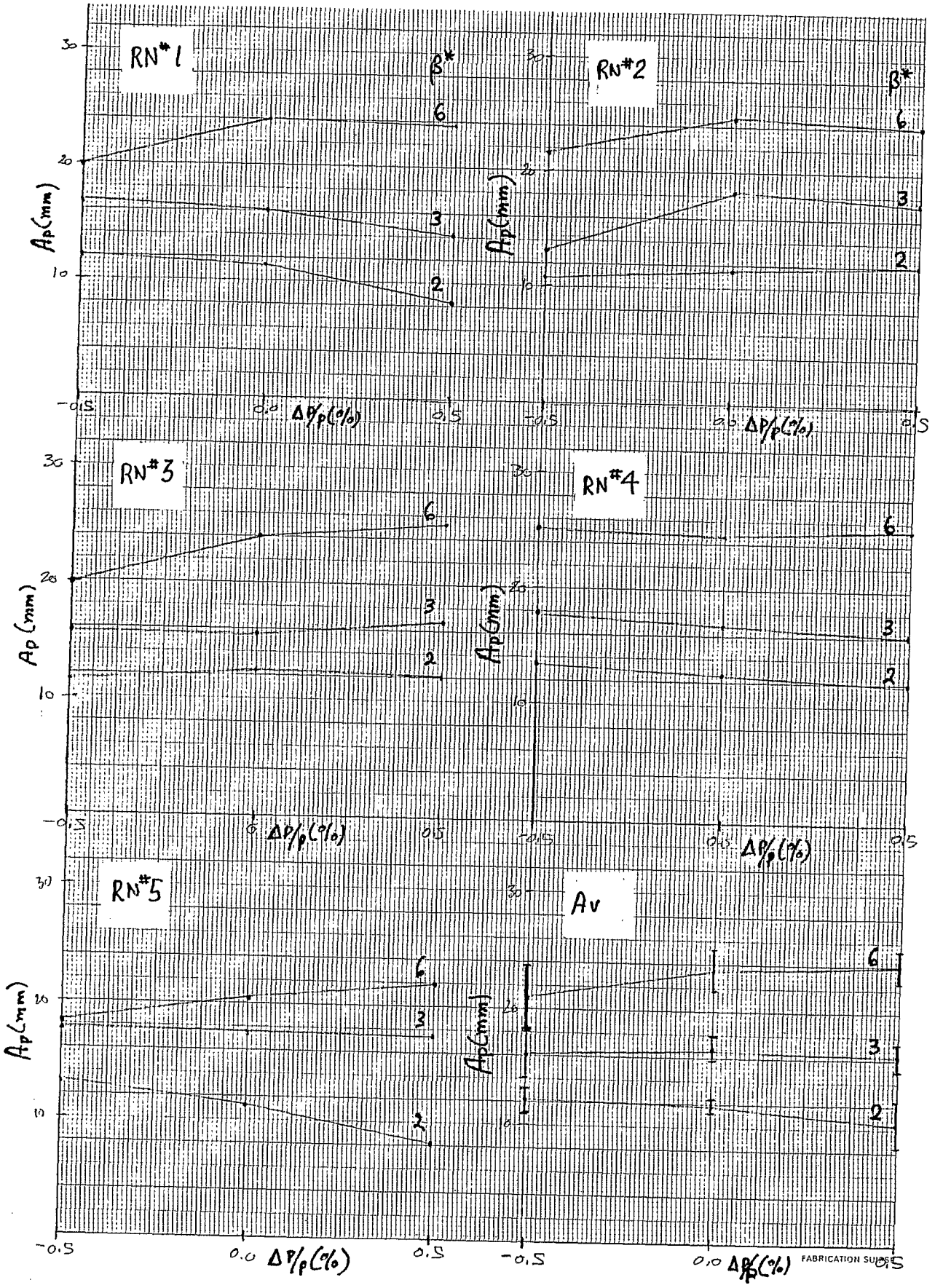


Figure 2 Physical aperture determination for each of the five random number seeds plus the average of the five determinations.