CLOSED ORBIT ADJUSTMENT

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1. Estimate of Closed Orbit Distortions

Quadrupole placement errors are likely to be the dominant source of closed orbit distortions. The mean square orbit displacement at a point where the amplitude function is β (and $\alpha = 0$) is

$$\langle x^2 \rangle = \frac{1}{4 \sin^2 \pi \nu} \frac{\beta}{2} \sum_i \beta_i q_i^2 \langle \delta_i^2 \rangle$$

$\langle \delta_i^2 \rangle$ = mean square position error of ith quadrupole

$q_i = B'_i \ell_i / B\rho$; ℓ_i = length of ith quadrupole

β_i = amplitude function at midpoint of ith quadrupole

For this estimate, parameters were obtained from a SYNCH printout provided during the study. In the tabulation below, Q4 is the quadrupole nearest to the intersection point.

Quad	B' (kG/m)	$\lvert q_i \rvert$ (m^{-1})	$\beta_i q_i^2$ (m^{-1}) (H)	(V)
Q4	-317.6	0.143	1.10	1.97
Q3	297.7	0.134	2.21	0.86
Q2	-459.8	0.069	0.04	0.20
Q1	0	0	0	0
normal F	660.0	0.115	0.56	0.10
normal D	-660.0	0.115	0.10	0.56

Note that if $\langle \delta_i^2 \rangle$ is the same for all quadrupoles, the contribution to $\langle x^2 \rangle$ from the intersection region quadrupoles is essentially the same as that of all the other quadrupoles combined.

The rms placement error has been estimated to be 0.35 mm.[1] at a point where β = 100 m, one would then have

1. G. Parzen, "ISABELLE Magnet Correction System", these Proc.

$x_{rms} = 13.7$ mm, $y_{rms} = 13.3$ mm

and in the normal cells, these displacements drop to about 9 mm at the focusing quad in each plane. At the crossing points, the rms displacements are 5 mm horizontally (at $\beta_H = 20$ m) and 2.7 mm vertically (at $\beta_V = 4$ m).

2. Correction System

Currently, it is proposed[1] that dipole windings be included in the main quadrupoles to permit steering of the beam. Here, it will be assumed that horizontal deflections are made at horizontally focusing quads, vertical deflections at vertically focusing quads. It will also be assumed that each such dipole can be powered individually.

The present plan calls for a maximum field of 1 kG in the normal cell quadrupoles. Taking an effective length of 1.3 m, at 30 GeV a dipole can then achieve a bend angle of 1.2 mrad. The phase advance in a normal cell is $\sim 90^{\circ}$; two dipoles 180° apart in phase will produce a 50 mm deflection at the quadrupole midway between them. This deflection is a factor of 5 larger than the rms displacement of the preceding section, thus the correction dipole strength is comfortably large at injection.

At 200 GeV, the same pair of dipoles could produce a deflection of $\sim$ 8 mm. This is still a comfortable correction capability, for based on observations at low energy, large closed orbit excursions will have been removed by quadrupole realignment.

The intersection regions present special requirements. Here vertical position control to a fraction of the beam height is needed. During stacking and acceleration, it will be desirable to have the capability of separating the two beams vertically. Horizontal displacement of the orbit may be used to shift the crossing point in azimuth. Correction dipole windings on the quadrupoles near the intersection region can be used for these purposes.

If three dipoles are employed to make a local orbit distortion, then the ratios of their deflection angles are

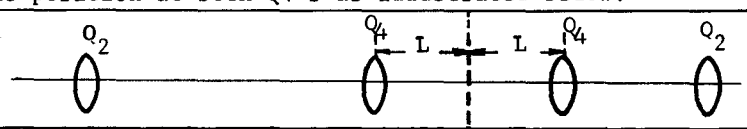
$$\frac{\theta_2}{\theta_1} = -\left(\frac{\beta_1}{\beta_2}\right)^{\frac{1}{2}} \frac{\sin \Psi_{13}}{\sin \Psi_{23}} \; ; \; \frac{\theta_3}{\theta_1} = \left(\frac{\beta_1}{\beta_3}\right)^{\frac{1}{2}} \frac{\sin \Psi_{12}}{\sin \Psi_{23}}$$

where Ψ_{ij} is the phase advance between the ith and j^{th} dipole. A vertical bump using Q2 and Q4 on one side of the insertion and Q4 in the other can be used to center the beam in the first Q4. Assigning θ_1 to Q2, then

$$\frac{\theta_2}{\theta_1} = 1.0; \; \frac{\theta_3}{\theta_4} = 1.5.$$

If the dipole winding on Q3 is capable of the same angular deflection as the windings on the normal cell quadrupoles, then at 200 GeV, a displacement of 7 mm will be produced at Q4. This would appear to be more than adequate.

Vertical position and angle control at the crossing point can then be effected by combining the two orbit distortions used for adjusting the position at both Q4's as illustrated below:



far left Q4	$\theta 1$	$\theta_2 = 1.0\ \theta_1$	$\theta_3 = 1.5\ \theta_1$	
far right Q4		$\theta_3 = 1.5\ \theta_1$	$\theta_2 = 1.0\ \theta_1$	θ_1
position	θ	$2.5\ \theta$ ($y = 5\theta L$)	$2.5\ \theta$	θ
angle	θ	$-0.5\ \theta$ ($\lvert y' \rvert = 0.5\ \theta$)	$0.5\ \theta$	$-\theta$

With the dipole strengths assumed above, excitation of maximum deflections in both rings would provide a vertical separation of up to 14 mm at 200 GeV, which is large compared with the rms beam height of $\sim \frac{1}{4}$ mm at that energy. The angular control on a single beam would be 0.09 mrad, a 1% adjustment.

In the horizontal plane, position adjustment in Q3 can be performed by using the nearest standard quad on the same side of the intersection, and both Q3's. For this arrangement (assigning θ_1 to the normal quad)

$$\frac{\theta_2}{\theta_1} = 0.37 \; ; \; \frac{\theta_3}{\theta_1} = 0.53 \; .$$

The displacement at Q3 can then be 11.6 mm at 200 GeV. Under this circumstance, the displacement at the intersection point is $\sim$ 7 mm, so if the three dipole bumps are combined, a horizontal displacement of $\sim$ 14 mm can be obtained. The crossing center could thereby be displaced by 1 m in either direction. When combined as an angle control, the direction of a single beam could be altered by up to 0.15 mrad.