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Optimization Of The Lattice For Intrabeam Scattering For Short Bunches Operation Mode (60 Degree Phase Advance Cell)

A. G. Ruggiero

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Collider Accelerator Department
Brookhaven National Laboratory

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OPTIMIZATION OF THE LATTICE
FOR INTRABEAM SCATTERING
FOR
SHORT BUNCHES OPERATION MODE
(60° PHASE ADVANCE CELL)

A.G. Ruggiero

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The Collider is made of 6 periods -
 Each period is made of an arc with
 radius of curvature $R_0 = 381.2325 \text{ m}$ and
 a long straight section of length $L_s = 289.7358 \text{ m}$
 In the arc we are going to install regular
 FODO cells each with length $2L$.
 The bending angle per half regular cell is

$$\theta = 2\pi/N \tag{1}$$

where

$$N = 2\pi R_0 / L \tag{2}$$

is the number of $1/2$ regular cells.

We require the phase advance per cell is 60° .
 For a thin lens approximation this gives:
 for the quadrupole gradient B'

$$\frac{B' l_q}{B\rho} L = 1 \tag{3}$$

l_q , quadrupole length

$B\rho$, beam magnetic rigidity

$$\begin{aligned}\beta_{\max} &= 2\sqrt{3} L \\ \beta_{\min} &= 2/\sqrt{3} L\end{aligned}\quad (4)$$

$$\begin{aligned}\eta_{\max} &= 5L\theta \\ \eta_{\min} &= 3L\theta\end{aligned}\quad (5)$$

Let us define the averages

$$\bar{\beta} = (\beta_{\max} + \beta_{\min})/2 = 2.3094 L \quad (6)$$

$$\bar{\eta} = (\eta_{\max} + \eta_{\min})/2 = 4 L\theta \quad (7)$$

Taking into account (1) and (2), (6) becomes

$$\bar{\eta} = 4 \frac{L^2}{R_0} \quad (8)$$

Therefore if the cell half-length L is given, we obtain $\bar{\beta}$ and $\bar{\eta}$ from (6) and (8).

This is shown in the Table at the end of the note.

We have done intrabeam scattering calculation at the computer for a smooth machine defined by the parameters $\bar{\beta}$ and $\bar{\eta}$. We have calculated the diffusion rate in energy τ_E^{-1} and betatron side τ_β^{-1} for a 0.001 Amp-particle bunched beam at 100 GeV/A for Gold ($A=197, Z=79$).

We have assumed a normalized emittance

$$E_N = 4\pi \text{ mm}\cdot\text{mrad}$$

and an rms energy spread within the bunch

$$\sigma_E/E = 4 \times 10^{-4}$$

The diffusion rates are shown in the Table. The energy diffusion rate decreases whereas the betatron diffusion rate increases with the half-length L of a cell.

These diffusion rates affect the luminosity lifetime with the same order.

For a luminosity of $\approx 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ one requires 57 short bunches each with $N = 6.24 \times 10^8$ and an rms bunch length of $\sigma_z = 10 \text{ cm}$. This corresponds to a peak current of 0.12 Amp-particle.

In the Table we give the luminosity

diffusion time

$$t_L = \frac{1}{120 (\tau_E^{-1} + \tau_\beta^{-1})}$$

As one can see the shorter the length cell the longer the luminosity lifetime -

Possibly the luminosity lifetime could be actually longer than the values reported by ~ 50% because of the long straight sections where the dispersion is zero and there is no local betatron diffusion due to intrabeam scattering -

Therefore a cell length of about $2L = 22\text{m}$ seems to be adequate for a luminosity lifetime of about one hour which is a long period of time compared to the filling time of 2×1 minute -

In the same Table we report the approximate estimate of the transition energy δ_T

$$\delta_T \approx \sqrt{R/\bar{\eta}}$$

where $R = 610.17\text{m}$ is the average radius -

Our choice, marked with a star, corresponds to $\gamma_T \approx 22$.

We also give the maximum coupling impedance Z/n allowed for ~~the~~ longitudinal beam stability according to the formula

$$|Z/n| \approx \frac{E |\eta|}{e I_p} \left(2 \frac{\sigma_E}{E} \right)^2 \frac{A}{Z^2} .$$

The beam we have specified above corresponds to a short bunch mode of operation as an invariant longitudinal emittance of

$$S = 0.25 \text{ eV/A-sec / bunch}$$

for 95% of the particle distribution.

Can one produce such a bunch from the AGS?

With our choice of $L \sim 11 \text{ m}$ we have

$$\beta_{\max} = 37.5 \text{ m}$$

$$\eta_{\max} = 1.54 \text{ m}$$

Let us consider the case of Gold at 5 GeV/A with a full momentum spread

$$\Delta p/p = 2 \times 10^{-3}$$

and

$$E_{H,V} = 0.8 \pi \text{ mm} \cdot \text{mrad}$$

The maximum beam full height is

$$a_v = 2 \times \sqrt{0.8 \times 37.5} \text{ mm} = 11 \text{ mm}$$

and the maximum full width is

$$a_H = 2 \sqrt{(1.54 \times 1)^2 + (0.8 \times 37.5)} = 11.4 \text{ mm}$$

or at most

$$a_H = \left[(1.54 \times 2) + 2 \sqrt{0.8 \times 37.5} \right] \text{ mm} = 14 \text{ mm}$$

Sketch of a Regular Cell (Approximated)

Take $L = 10.8 \text{ m}$

Quadrupole length $l_q = 1.2 \text{ m}$

B_p for Gold at 100 GeV/A = 800 T-m

Quadrupole Gradient = 62 T/m

Bore Radius = 4 cm

Field at Pole Tip = 2.5 T

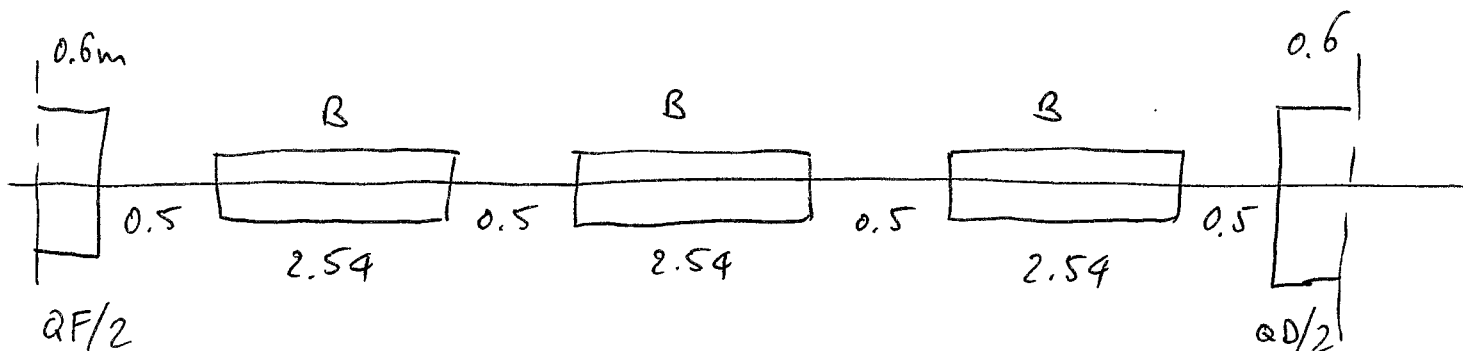
$N = 220$ half-cells

$\theta = 28.56 \text{ mrad}$ ~~the~~ bending angle / ~~the~~ half-cell

Assume 3 bending magnet / half cell

Take $B = 3.0 \text{ T}$ then $3l_B = 7.616 \text{ m}$

That is $l_B = 2.54 \text{ m}$



I believe one single curved dipole is better

L	$\bar{\beta}$	$\bar{\sigma}$	σ_E^{-1}	σ_{β}^{-1}	t_L	δ_T	Z/n	
m	m	m	h^{-1}	h^{-1}	hours		ohm	
2.16	5	0.05	-	-	-	110	0.3	
4.33	10	0.2	-	-	-	55	3.9	
6.49	15	0.44	.0044	.0034	1.1	37	10.6	
8.66	20	0.786	.0033	.002 / .0073	1.5 / 0.8	28	19.8	
10.82	25	1.23	.0025	.0051 / .01	1.1 / 0.7	22	33	*
12.99	30	1.77	.002	.0076 / .0119	0.9 / 0.6	18.6	47	
15.15	35	2.41	.0016	.0133	0.56	15	64	
17.32	40	3.146	.0013	.0143	0.53	14	84	
19.48	45	3.98	.0011	.0181	0.43	12.4	108	
21.64	50	4.92	.0009	.0211	0.38	11	137	