Problems Lecture 1: Lattice Design

1) A transport lattice with no acceleration consists of FODO cells with quadrupole spacing $L = 10\,\mathrm{m}$ and focal distance $f = 7\,\mathrm{m}$. How large is the phase advance?

2) Estimate the RMS beam jitter at a position with $\beta(s_2) = 1\,\mathrm{m}$ if one quadrupole jitters 450° upstream with a focal length $f = 7\,\mathrm{m}$ and $\beta(s_1) = 10\,\mathrm{m}$. The quadrupole jitter amplitude has an RMS of $1\,\mu\mathrm{m}$.

3) Calculate the average beta-function in a thin lens FODO lattice as a function of $\hat{\beta}$, $\check{\beta}$ and L/f

4) How much does a cavity with tilt $\theta \ll 1$ deflect the beam?

Solutions

1) We use

$$\cos\mu = 1 - \frac{L^2}{2f^2}$$

$$\Rightarrow \mu = \arccos\left(\frac{1}{2}\right) \approx 91.169^\circ$$

2) The angular deflection is given by the offset δ and the focal strength f

$$y' = \frac{\delta}{f}$$

we transform into nromalised phase space

$$y'_N = \sqrt{\beta(s_1)}\frac{\delta}{f}$$

450° downstream this is

$$y_N = \sqrt{\beta(s_1)}\frac{\delta}{f}$$

which translates into

$$y = \sqrt{\beta(s_1)\beta(s_2)}\frac{\delta}{f}$$

inserting number we find

$$y \approx 0.45\delta$$

hence the RMS jitter $\sigma_{y,jitt} = 0.45\,\mu\mathrm{m}$.

Solutions

3) We will integrate from the centre of a defocusing quadrupole (at $s = 0$) to the centre of the next focusing quadrupole (at $s = L$). In the centre of the defocusing quadrupole we have $\beta = \check{\beta}$ and $\alpha = 0$. We calculate the Twiss parameters immediately after the quadrupole (at $\epsilon \to 0$):

$$\begin{pmatrix} \beta(\epsilon) & -\alpha(\epsilon) \\ -\alpha(\epsilon) & \gamma(\epsilon) \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 1/(2f) & 1 \end{pmatrix} \begin{pmatrix} \check{\beta} & 0 \\ 0 & 1/\check{\beta} \end{pmatrix} \begin{pmatrix} 1 & 1/(2f) \\ 0 & 1 \end{pmatrix}$$

$$\Rightarrow \begin{pmatrix} \beta(\epsilon) & -\alpha(\epsilon) \\ -\alpha(\epsilon) & \gamma(\epsilon) \end{pmatrix} = \begin{pmatrix} \check{\beta} & \check{\beta}/(2f) \\ \check{\beta}/(2f) & 1/\check{\beta} + \check{\beta}/(2f)^2 \end{pmatrix}$$

now we calculate beta along a drift using

$$\begin{pmatrix} \beta(s) & -\alpha(s) \\ -\alpha(s) & \gamma(s) \end{pmatrix} = \begin{pmatrix} 1 & s \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \check{\beta} & \check{\beta}/(2f) \\ \check{\beta}/(2f) & 1/\check{\beta} + \check{\beta}/(2f)^2 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ s & 1 \end{pmatrix}$$

$$\beta(s) = \check{\beta} + \frac{\check{\beta}}{f} s + \left(\frac{1}{\check{\beta}} + \frac{\check{\beta}}{4f^2} \right) s^2$$

$$\langle \beta \rangle = \frac{1}{L} \int_0^L \beta(s) ds = \check{\beta} + \frac{\check{\beta}}{2f} L + \frac{L^2}{3} \left(\frac{1}{\check{\beta}} + \frac{\check{\beta}}{4f^2} \right)$$

to avoid to much calculation we exploit

$$\beta(L) = \hat{\beta} = \check{\beta} + \frac{\check{\beta}}{f} L + \left(\frac{1}{\check{\beta}} + \frac{\check{\beta}}{4f^2} \right) L^2$$

hence

$$\langle \beta \rangle = \frac{2}{3} \check{\beta} + \frac{1}{3} \hat{\beta} + \frac{L}{6f} \check{\beta}$$

Solutions

4) The deflection of the beam by a single structure of length L and gradient G with tilt $\theta \ll 1$ is

$$\delta y' = \frac{eGL}{2}\frac{1}{E}\theta = \frac{\delta}{2}\theta$$

δ is the relative acceleration by the cavity.

To calculate this we have to add three contributions:

The kick applied by the central part of the structure is

$$\delta y'_c = \frac{eGL}{E}\theta = \delta\theta$$

The field at the entrance give a thin lens kick, since the particle has an offset with respect to the axis of the structure of $y = L/2\theta$

$$\delta y'_1 = -\frac{eG}{2E}\frac{L}{2}\theta = -\frac{1}{4}\delta\theta$$

The offset at the exit is $y = -L/2\theta$, hence

$$\delta y'_2 = \frac{eG}{2E}\frac{-L}{2}\theta = -\frac{1}{4}\delta\theta$$

So in total

$$\delta y' = \delta'_c + \delta'_1 + \delta'_2 = \frac{\delta}{2}\theta$$