

Accelerator Lattice Design – Part I Lattices

– Laboratory Exercise – Ralph J. Steinhagen, CERN

HERMAN[®]

by Jim Unger



“I think my test results are a pretty good indication of your abilities as a teacher.”

- Acknowledgements and credits to: W. Herr, B. Holzer, A. Streun, A. Wolski

Excercise I – Warm-up

- Show that the FoDo lattice transfer matrix can be written as:

$$M_{FoDo} = \begin{pmatrix} 1 - \frac{L^2}{2f^2} & L \left(1 + \frac{L}{2f} \right) \\ \left(\frac{L^2}{2f^3} - \frac{L}{f^2} \right) & 1 - \frac{L^2}{2f^2} \end{pmatrix}$$

- What is the stability criterion for such a cell?
- Calculate the phase advance per FoDo cell as a function of 'f' and 'L'?
- Have a look and check-out the supplied MAD-X examples from the introduction
 1. → check that you can execute MAD-X properly and that you can open postscript files
 2. → get “hints” in case you are stuck with the following exercises

Exercise II

- We love to build a circular lepton accelerators. Let's design one with the following basic parameters:
 - Choose between a momentum p_0 of
 - a) 3-4 GeV/c (storage ring)
 - b) 0.1-3 GeV/c (ramping synchrotron)
 - c) 120 GeV/c (collider)

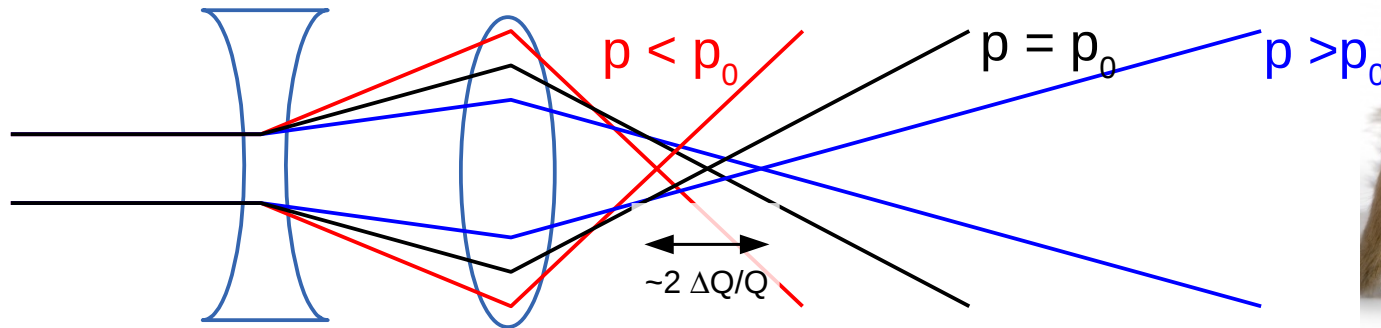
} take a pick and stick with your choice for the next exercises
 - We have only normal conducting magnets at our disposal with max. field strengths:
 - for dipole magnets: $B_{\max} \leq 2 \text{ T} \ \& \ l_d \leq 5 \text{ m}$
 - for quadrupole magnets: $\text{dB}_y/\text{dx}|_{\max} \leq 25 \text{ T/m} \ \& \ l_q \leq 1.5 \text{ m}$
 - Calculate and decide for the required circumference so that you have about ~30% margin for other insertions (also, pick a nice round number).
 - We start with a $\mu=90^\circ$ FODO lattices: how many cells do we need for $\beta|_{\max} < 300 \text{ m}$
- Define a lattice according to the boundary conditions, and find the optics. Implement and verify your design with MAD using thin (easier for tracking) or thick (more correct) lenses. Explain your choices!

Exercise III

- Continue with the lattice you just designed and modify it so the maximum betatron function β_{\max} is less than 200 m and possibly around 100 m.
 - Keep circumference and energy constant, all other parameters may be modified.
- Do some simple particle tracking and plotting with MAD (use demo in slides)
 - Is the particle motion stable/unstable? What is the maximum stable amplitude?
- The fractional betatron tunes are likely too close to a resonance, correct them to $q_x=0.29$ and $q_y=0.22$.
 - MAD-X variables for the tunes are 'Q1' and 'Q2' (use matching code snippet from the lecture). N.B. check that your (de-)focusing quadrupole strengths are defined via ':='
 - optional: you may deliberately set the fractional tunes on resonance, e.g. to $q_x=0.31$ and $q_y=1/3$ and check the particle tracking results.

Recap: Tune & Chromaticity I/III

- Light optics analog: chromatic error



chromaticity

- Tune spread $\Delta Q/Q$ dependence on momentum spread $\Delta p/p$:

$$\Delta Q := Q' \cdot \frac{\Delta p}{p} \quad \text{or:} \quad \frac{\Delta Q}{Q} := \xi \cdot \frac{\Delta p}{p}$$

defines: (normalised) 'chromaticity' Q' (ξ)

→ also 1st order measurement principle



Exercise IV – Our first non-linear Element

- Somebody indicated that due to “collective effects” (e.g. finite vacuum chamber resistance) the beam becomes unstable for chromaticities $Q' < 0$. However, this can be fixed through sextupoles in locations with non-zero dispersion → more on this on Monday
- Check the (natural) chromaticity of your lattice
 - MAD variables: 'DQ1' and 'DQ2' (part of the 'Twiss;' output).
 - Compare the results with your calculations.
 - Is the Chromaticity positive or negative?
 - What is the maximum stable particle amplitude without sextupoles (->tracking)?
- Replace a single FoDo cell with a cell containing (de-)focusing sextupoles next to a (de-)focusing quadrupole.
 - Assume zero-length or very short (i.e. 20 cm) sextupoles. There isn't a limit on the sextupole gradient for the following tests.
 - Match the chromaticity to zero using the two sextupole families. N.B. you may want to match Q1 & Q2 at the same time to fix them to your previous tunes.
 - What is the maximum stable particle amplitude with sextupoles?
- Add sextupoles to all FoDo cells and re-match the tune and chromaticity
 - Re-do the previous item (match Q,Q', maximum stable particle amplitude).