Introduction to Accelerator Physics
PHY 7656 /4456 Cornell 2017

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Takehome final, due 12:20pm Thursday 12/14/2017

Help:
You may use all handouts, books, etc. You may use Mathematica or similar high-level programs, and you may use other beam optics programs like TAO. Feel free to contact me if you have problems.

Exercise 1 (Simple accelerators): Assume that the earth has an exact dipole magnetic field which is oriented parallel to the rotation axis. As in homework 2, assume that the field at the pole is about $2 \cdot 10^{-5}$T. Would the beam motion for protons be stable or unstable in the horizontal and vertical plane?

Exercise 2 (Linear optics):
You are given a ring shaped tunnel with circumference of 300m. Design a storage ring that has that circumference. You may use thin lens approximation for each optical element. Make very clear what length and strength you use for all of your elements so that your calculation can be checked.
(a) Use a regular FODO structure in the arcs. Give some argument for the parameters you choose.
(b) Insert an interaction region (IR) with beta functions of $\beta_x^* = 0.2$m and $\beta_y^* = 0.05$. It has been found in a previous homework that a low beta insertion with phase advances of π needs three free quadrupoles at each side of the IP. Explain why two quadrupoles on each side are sufficient when you drop the phase advance requirement. You are free to use a 4 or a 6 magnet interaction region. Finding the strength of 4 quadrupoles by fitting may however be easier.
(c) The dispersion and its slope should be zero at the interaction region and you need to use variable dipoles to match the dispersion from the FODOs to the interaction point (IP). The so called missing magnet scheme brings the dispersion to 0 at the IP. In this scheme the second last FODO has no bend between its two quadrupoles, so that the 3rd and 4th bend on both sides of the IP are missing. This works very well with thin lens quadrupoles. With

long quadrupoles it is good to try out to have other sets of 2 magnets missing in the first 2 FODOs before the IP.

Exercise 3 (Nonlinear optics):
Compute the natural chromaticity. Correct the chromaticity to 0 with one sextupole (you may use a thin lens approximation) after each quadrupole of the FODOs, but not after the quadrupoles of the IR. Why would a sextupole so close to the IR not help with correcting the chromaticity?

Exercise 4 (Working point): (a) Choose a working point for the horizontal and vertical tunes and change all focusing FODO quadrupoles together and all defocusing FODO quadrupoles together to operate the accelerator at your chosen tunes. Plot the beta functions and the dispersion after this change.
(b) Is the beta function or the dispersion more sensitive to changes?
(c) Re-match the interaction region to the slightly changed FODO.
(d) Rematch the chromaticities. Are the chromaticities sensitive to the changes?

Exercise 5 (Dynamic Aperture):
(a) Track particles with only horizontal amplitudes and estimate the horizontal dynamic aperture.
(b) Track particles with an energy change and show how the dynamic aperture changes.
(c) Choose a working-point close to $\nu_x = \frac{1}{3}$ and check whether you can observe unstable fixed points.

Exercise 6 (Optimization):
(a) Optimize all parameters of the accelerator that you can think of in order to make the horizontal dynamic aperture without energy spread as large as possible. Adding other nonlinear elements is also permitted. The only requirements are $\beta_x^* = 0.2$m, $\beta_y^* = 0.05$m, $\eta_x^* = 0$, $\eta_y^* = 0$, $\xi_x^* = 0$, and $\xi_y^* = 0$.
(b) Don't give up, because a prize is waiting for the largest on-energy horizontal dynamic aperture !