Advanced Accelerator Physics and Accelerator Simulation Take-home Final Exam

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Help:
You may use all handouts, books, etc. You may use the rudimentary thin lens beam optics Mathematica notebook on the class web page, and you may use other beam optics programs like TAO. You will see comments bellow that should help you with using the Mathematica notebook or the TAO files. 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. 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. (**TAO:** The 2nd, 3rd, and 4th TAO directory show you how to optimize a FODO for the phase advance of your choice.) (**Mathematica:** The section "Parameters" specifies some constants used in the notebook. The section "Formulas" specifies some formulas that will be used in the notebook. The section "FODO" shows you how to specify a FODO cell and how to compute beta functions within it. The section "Arc of Half the Ring" shows you how to build the ring from many FODO cells.)
(b) You want to insert an interaction region (IR) with beta functions of

$\beta_x^* = 0.2\text{m}$ and $\beta_y^* = 0.05$. It has been found in homework 9 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. Matching 4 quadrupoles may however be easier.(**TAO:** The 5th and 6th TAO directory show you how to specify an interaction region and how to insert this region into your ring that consists of FODO cells.) (**Mathematica:** The sections "Interaction Region" and "Lattice" show you how to produce a FODO base ring with interaction region.)

(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. (**TAO:** The 5th and 6th TAO directory show you how to obtain zero dispersion at the IP with a suitable missing magnet scheme.) (**Mathematica:** The sections "Dispersion" shows you how to produce an interaction region with no dispersion.)

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. (**TAO:** The 7th TAO directory shows you how to assemble the full ring, and the 8th shows you how to place sextupoles and how to correct the chromaticity.) (**Mathematica:** The sections "Chromaticity" shows you how to place sextupoles and how to correct the chromaticity.)

Exercise 4 (Working point): (a) Choose a working point 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. (**TAO:** There is no directory that changes the tune of the ring, but you would use exactly the same strategy that was used when you fitted the phase advance of a single FODO cell only that now the phase advance of the full ring is fitted.) (**Mathematica:** The sections "Tune" shows you how to change the tune and observe changes in the Twiss parameters.)
(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 this aperture changes.
(c) Choose a working-point close to $\nu_x = \frac{1}{3}$ and check whether you can observe unstable fixed points that correspond the the computed resonance terms.

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. 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 dynamic aperture !