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Exercises for the optics course at the CAS 2015 on Otwock

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Abstract

In this paper we formulate the problems and exercises for the Optics Course at the Advanced Level CERN Accelerator School 2015 on Otwock.

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1 Introduction

At the CERN Accelerator School 2015 on Otwock, a course is held on optics design. This course is intended as an introduction for accelerator physicists who want to start the design of accelerator optics as well as for people from other fields who would like to get a basic knowledge of the principles of accelerator design.

The aim is that the participants design a realistic accelerator optics, following plenary lectures on lattice cells [1], insertions [2] and imperfections [3, 4]. This should be done following a series of steps in form of exercises the participants have to solve and implement in an accelerator design program (MAD-X) [5, 6, 7].

In this paper we formulate the problems and exercises for this course.

2 Exercise 1

2.1 Problem:

Design a machine for protons at a momentum of 20 GeV/c with the following basic parameters:

- Circumference = 1000 m,
- Quadrupole length L_q = 3.0 m,
- 8 FODO cells.
- Dipole length is 5 m, maximum field is 3 T

Apply the knowledge from previous lectures at this school and define a lattice cell according to the boundary conditions (position of dipole magnets and quadrupoles) and find the optics (strength of dipoles and quadrupoles) so that $\beta_{max} \equiv \hat{\beta}$ is around 300m. Implement it in MAD format using thin lenses for all elements and verify the calculations.

3 Exercise 2

3.1 Problem:

Assume the aperture requires a beam size 10 σ $\leq$ 31.4 mm. Start with the lattice from exercise 1 and modify it so the maximum betatron function $\hat{\beta}$ satisfies this requirement (please use rounded numbers for convenience). The normalized beam emittance is ϵ_n = 2.0 μm.
The circumference and the energy must not be changed, all other parameters may be modified.

4 Exercise 3

4.1 Problem:

Start with the lattice from exercise 2 and modify it so you can correct the chromaticity for both planes to zero. Try first to calculate approximately the required strengths. Implement your correction scheme in your previous MAD files and verify your calculation. Use MAD to compute the exact strengths required by matching the global parameters Q'_x and Q'_y (in MAD names: DQ1 and DQ2). Compare the results with your calculations.

5 Exercise 4

5.1 Problem:

Start with the lattice from the previous exercise and assume random misalignments of the quadrupoles of r.m.s. 0.1 mm in the horizontal and 0.2 mm in the vertical plane. Calculate the expected r.m.s. orbit and verify with MAD.
Remember: misalignments are established with the command EALIGN.

6 Exercise 5

6.1 Problem:

Start with the lattice from the previous exercise and add the necessary equipment to be able to correct the closed orbit in both planes, (using MAD). Estimate first the maximum necessary strength of the orbit correctors assuming a maximum quadrupole displacement of 1 mm.
Use MAD to correct the orbit in both planes.

7 Exercise 6

7.1 Problem:

The purpose of this exercise is to insert dispersion suppressors into the existing regular lattice. Start with the lattice from the previous exercise and first double the circumference to 2000 m. Change the phase advance to $\phi = 60^o$ per cell. Insert two straight sections (each of 2 cells): i.e. cells without bending magnets but keep the same focusing of the quadrupoles. Insert the two straight sections opposite in azimuth in the ring. Modify now the lattice to keep the horizontal dispersion function small ($<$ 1-2 m) along this straight section, i.e. set up a dispersion suppressor. You can do this by adding or removing bending magnets or changing the bending radius of some or all the bending magnets.
At this stage do not change the focusing properties in any of the cells. Such straight sections with very small dispersion are very useful for the installation of RF equipment, wigglers, undulators, beam instrumentation, collimation systems etc., or to house an experiment.
As a second exercise, replace all bending magnets presently implemented as thin lenses, by thick lenses, i.e. define them as SBEND with the same angle. Look at the result and explain what you observe.

8 Exercise 7

8.1 Problem:

Start from the previous lattice and design a symmetric insertion with a low-β section in a dispersion free region. The β should be small at least in one plane and should have a waist at an ”interaction point”. Choose the low-β (usually called β^*) at your own descretion. Think about the options $\beta_x^* = \beta_y^*$ or $\beta_x^* \neq \beta_y^*$.
Two options:

- Try to design the insertion yourself
- Use an already prepared example sequence and try to match

9 Exercise 8

9.1 Problem:

Use the lattice from exercise 6 and set up a single particle tracking to study the stability of the beams. use the thin lens version for tracking with madx.

- Select appropriate particle amplitudes
- Change to tune and sextupole strengths to observe the effect
- Try to track with a thick lens lattice with PTC
- Change the tunes to see the effect
- Change the strengths of the chromaticity sextupoles to see the effect

References

[1] B. Holzer, *Lattice cells*, this school.

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[4] R. Tomas, *Linear imperfections*, CAS 2014, Prague.

[5] *The MAD-X Home Page, version April 2015*, $http://cern.ch/mad/$.

[6] W. Herr, *MAD-X Tutorial*, this school.

[7] W. Herr, *A MAD-X Primer*, CERN-AB-2004-027-ABP and Proceedings, CAS 2003, Zeuthen.