Simulation of the MAX IV 3 GeV ring

An accelerator is built around a number of components. To get a picture of the operation of the accelerator one builds a model of the machine and uses this model to study different phenomena. Different accelerators have different aims, and thus the models, the way of doing models and the studies vary.

The machine in this case is the MAX IV 3 GeV storage ring. It is 528 m in circumference and can accelerate electrons to 3.0 GeV.

These machines are most important when operating steadily over long periods and the acceleration process is of less interest. In a first assumption one can thus study these machines without acceleration. In this way the machine is defined by the magnets steering the particles (in this case electrons) down the accelerator. To build a model of this machine we first need a description of the magnets and then a layout of where to place the magnets (lattice). To manage analyzing the machine during 2 hours an almost complete lattice file is available describing the MAX IV 3 GeV ring.

Calculations over particle transport in accelerators follows in a first approximation a rather "simple" matrix model, which has been discussed in the beam dynamics. Despite the relative simplicity the calculations includes many calculations which rapidly grow difficult to do by hand. Different program codes exist for the purpose and the most of them manage to calculate additional phenomena for the accelerators, beyond the most immediate matrix results. WINAGILE is an accelerator code developed for the CERN Accelerator Schools by Phil Bryant. WinAGILE is not the only code available. OPA is another code with a user friendly interface, while more detailed studies of the dynamic aperture and lifetime limitations are carried out with computer codes with terminal based input and output, for example ZAP, TRACY and MAD.

What to do

You should run WinAGILE, extract answers to a number of questions and discuss the results. You can work together in pairs. Start by reading section 1-2.1 in Tavares et al., "The MAX IV storage ring project", to learn about the purpose and the linear optics of the MAX IV 3 GeV storage ring.

Questions

1. Open the lattice file in Winagile. The file describes one achromat. A table of the achromat is also found in the appendix of these instructions. Compare the element parameters in the file to the parameters in the appendix. For the entrance and exit dipoles the bending angles are given, but for the center dipoles you have to calculate and insert the value. All the center dipoles have the same bending angle. You need to use a large number of decimals (around 10 or so). Does your calculated value agree with what is stated in the Tavares article?

   To change the lattice file:
   file->edit
   Double click the value you want to change. Input the value. Click ok.
   Check_Data->Check_with_decompression->Yes

2. Extract the transfer matrix for one of the quadrupole magnets.

   Calculations->Matrices-> (Check that you have 3 GeV electrons) ->Double click on the line of the element you are interested in

   How can you see from the matrix in which plane it is focusing? Calculate the focusing of this magnet from the matrix and compare to the value in the appendix. Sometimes different sign conventions are used for quadrupole strength. Which are the conventions in these cases? Would the thin lens approximation be a good approximation for this magnet?

3. Ask Winagile to find the solution for a ring with this lattice.

   Calculations->Ring or matched section
   Continue->Ok

   Plot the layout. Can you distinguish the different parts of the achromat?
   Graphs->2d Geometry

4. Extract the transfer matrix for the entrance dipole. Is this a pure dipole? If not, in which plane does it focus?

   In the window "Rings and matched sections" double click the line for the element.

5. Go to the end of the file by scrolling or pressing "end" in the lower right corner. How many achromats do you need to make a complete ring? Does this agree with the Tavares article? What are the tunes of the ring? Does this tune agree with the Tavares article? If not, can you think of a reason why?

6. Plot the tune diagram. Is it a good working point? Compare to the working point of the real machine.

   To plot the tune diagram you have to run the complete machine which is 20 times the input file you have.
   Options->Back to main window
   File->Edit
   Mark all elements in the lattice.
   Structures->Repeat 'n' times: input 20 times -> Ok
   Check_Data->Check_with_decompression->Yes
   Calculations->Ring or matched sections
   Graphs->Tune diagram

7. Plot the twiss parameters and the dispersion. This is easier to see if you change the range to only show one achromat.

Graphs->Twiss transverse parameters
The range can be changed in the bottom of the graph

Where is the beam big/small? Can you with this information say what the beam size is?

What does the dispersion mean? Does it exist in both transverse planes? If not, why?

8. Track a single particle (example: x=0, x'=0.001, y=y'=0) one turn in the machine. Look at the orbit. Calculate the number of oscillation periods? What does this say about the tune? Compare to tracking a particle in the vertical plane.

   Calculations I->Tracking single particles (enter data) -> Continue
   Graphs->Trajectories, transverse

9. Track a particle with x=x'=y=y'=0, but a deviation in energy (example 0.001). Look at the orbit. Do you recognize the shape from somewhere else? It is easier to see if you change the range to one achromat.

   Calculations I->Tracking single particles (enter data) -> Continue
   Graphs->Trajectories, transverse

10. Track a beam of particles (emittance= 10, at least 10 beamlets).

    Calculations I->Tracking transverse distributions->Continue
    Beams->(enter values, examples: emittance=10, beamlets=10)->Ok->Ok
    press "Step" multiple times.
    Press "Phase space" if desired. Press "Real sp" to switch back.

    For the start point, how does the beam look in real space? An in phase space? Compare with the twiss parameter plots above and see if the two pictures agree.

    Go to element 9. How does the beam look in real space? An in phase space? Compare with the twiss parameters.

    Step onwards from element 9. How does the beam look in real space? An in phase space? Compare with the twiss parameters. Sometimes you need to step through the drift after a magnet to see the effect.

11. Increase the emittance. Compare with the previous cases. What does this imply for the performance of the machine?

Appendix

One (simplified) achromat of the MAX IV 3 GeV storage ring

	Element	Length [m]		Bend [°]	k []
1	ll	2.5			
2	l1	0.175			
3	qfend	0.25			3.533676
4	l2	0.225			
5	qdend	0.25			-2.23958
6	l3	0.006			
7	dm	0.75432		1.5	-0.54525
8	l4	0.46268			
9	ls	1.302			
10	qfm	0.55			2.061576
11	l5	0.51311			
12	d0	1.22387		Calculate	-0.70480
13	l5	0.51311			
14	qf	0.55			2.202441
15	l5	0.51311			
16	d0	1.22378		Calculate	-0.70408
17	l5	0.51311			
18	qf	0.55			2.202441
19	l5	0.51311			
20	d0	1.22378		Calculate	-0.70408
21	l5	0.51311			
22	qf	0.55			2.202441
23	l5	0.51311			
24	d0	1.22378		Calculate	-0.70408
25	l5	0.51311			
26	qf	0.55			2.202441
27	l5	0.51311			
28	d0	1.22378		Calculate	-0.70408
29	l5	0.51311			
30	qfm	0.55			2.061576
31	ls	1.302			
32	l4	0.46268			
33	dm	0.75432		1.5	-0.54525
34	l3	0.006			
35	qdend	0.25			-2.23958
36	l2	0.225			
37	qfend	0.25			3.533676
38	l1	0.175			
39	ll	2.5			