Accelerator Physics Exercises

- *Work to be handed in before tutorial on - 13 Jan 2016*

The aim of Hilary Term's work is to prepare a Student Design Project as part of the Future Circular Collider (FCC) study.

The FCC study is developing options for potential high-energy frontier circular colliders at CERN for the post-LHC era. The study includes a hadron collider (*FCC-hh*), a lepton collider (*FCC-ee*) and an electron-hadron collider (*FCC-he*). It has been launched as result of the recommendation made in the 2013 update of the European Strategy for Particle Physics.

The Student Design Project will concentrate on the *FCC-ee* in the beam energy range of 40 GeV to 175 GeV in a new 80-100 km circumference tunnel for the study of physics at high energies in electron-positron collisions. This, along with its detectors, will determine the basic requirements for the tunnel, surface and technical infrastructures.

A description of the FCC in general is available at:

https://espace2013.cern.ch/fcc/Pages/default.aspx

and details of the *FCC-ee* study are available at

https://fcc.web.cern.ch/Pages/Lepton-Collider.aspx

Question 5.1 (The Introduction)

Imagine you are writing an introductory section of the Student Design Report. Describe clearly and in detail the following:

(a) The physics that can be addressed by the *FCC-hh*, *FCC-ee* and *FCC-he*.

(b) The *FCC-ee* performance requirements and overall configuration.

(c) Limitations and issues arising from synchrotron radiation emission.

(d) The particle beam requirements for both the *FCC-hh* and *FCC-ee*. Compare the two particle beam options and elaborate the pros and cons of each.

(e) The motivation and uniqueness of the *FCC-ee* compared to the completed LEP programme and to a possible future Linear Collider – the International Linear Collider (ILC) and the Compact Linear Collider (CLIC).

Question 5.2 (The Lattice)

(a) The *FCC-ee* parameter report states that the number of arcs and long straight sections (LSS) is currently set to 12. The length of each LSS is 1.5 km and the length of each arc is 6.8 km, leading to a total machine length of 100 km. For a filling factor of 0.84 the report states that the corresponding bending radius is 11 km and the required bending field in the dipole magnets ranges from 130 to 540 G. Repeat the calculation for bending field strength for 45.6 GeV and 175 GeV beams, showing the working of this calculation.

(b) As a next step, scare yourself by looking at the provided lattice file called "FCCee_t_45_16_cw_nosol.seq". Then let us ignore it and start building our lattice from scratch. Create a MAD-X input file (based on FODO2.MADX that was used as an example in class), which creates the basic arc cell with a length of 50m, and a 90 degree phase advance. QF should be 3.5m and QD 1.4m long, with 4 × 10m dipoles. Make the drifts evenly spaced throughout. (You do not need to include sextupoles just yet, we will add those later). Adjust the quadrupoles to match the phase advance to 90 degrees in both planes.

(c) Next, save the file in a different name and re-match the cell to achieve phase advances of 79.2 degrees (x) and 60 degrees (y). This represents the other current arc cell option.

(Include the MAD-X input files, solved quadrupole values and relevant output files/plots in your solutions for (b) and (c)).

For clarification do not hesitate to contact Suzie Sheehy - suzie.sheehy@physics.ox.ac.uk

Question 5.3 (The Cavities)

It has been suggested that the *FCC-ee* could use an RF system operating at 800 or 400 MHz (the LHC frequency).

a) Revisit the lectures on RF cavity design & modeling and study in particular the slides showing the pillbox and elliptical-type cavities. Considering a 400 MHz RF frequency, estimate analytically the diameter of a pillbox cavity at this frequency (mode TM_{010}). Assuming this cavity accelerates relativistic electrons (β=1), model this cavity in *SuperFish*. Assume it is made of copper, it operates at room temperature, it has an axial electric field of 1 MV/m and a length of $\lambda/2$, where λ is the RF wavelength. Plot the electric field on axis and present the dissipated power in the cavity walls, the transit time factor, the effective shunt impedance per unit length (ZTT) and the quality factor Q. What would be the energy gain of an electron passing through the cavity for a synchronous phase ϕ=0. Start from the examples given in the tutorial.

b) Assuming an accelerating field of 5 MV/m and a relativistic β of 1, model a single cell superconducting elliptical cavity at 800 MHz. What is the Q of this cavity? Plot the electric field on axis. How many such cavities would be needed to provide a total RF voltage of 10 GV? How can the number of cavities be reduced? Start from the examples given in the tutorial.

c) Starting from the single cell elliptical cavity, model a multi-cell cavity in *Superfish*. You can choose the number of cells. Present your model, and plot the electric field on axis. What is the Q of this cavity, the ratio of peak fields (Bmax/Emax) and the peak to average electric field ratio (Emax/E0)? To model multi-cell elliptical cavities, you will need to add the "NumberOfCells" keyword to your single cell model and use the "ELLCAV.EXE" solver. Start from the examples given in the tutorial.

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