Accelerator Physics Exercises No. 5

- Work to be handed in on 18 January 2018

The aim of Hilary Term's work is to prepare a Student Design Project as part of the Higher-Energy Large Hadron Collider (*HE-LHC*), which is 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 also 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 and a Conceptual Design Report will be completed in 2018.

The Student Design Project will concentrate on the *HE-LHC* and the investigation of a high-field proton-proton collider in the LHC tunnel operating at a centre-of-mass energy between 26 TeV and 33 TeV. The *HE-LHC* will be based on dipole magnets between 16 T and 20 T that are being developed for the *FCC-hh* and is an extrapolation from the High-Luminosity LHC (*HL-LHC*) and the developments for the *FCC-hh*.

A description of the *FCC* in general is available at:

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

and details of the *HE-LHC* study are available at

http://cds.cern.ch/record/1344820

Question 5.1 (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 *HE-LHC*.

(b) The motivation and uniqueness of the *HE-LHC* compared to the *LHC* and to the *FCC-hh*.

(c) The *HE-LHC* performance requirements and overall configuration.

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

Question 5.2 (The Lattice)

(a) Study the *HE-LHC* lattice files. Create a MADX input file with just one basic straight cell (with no bending) and one basic arc cell. Use MADX to calculate and plot the periodic beta functions and dispersion in each cell. The latest lattice is V0.2 and is available at

http://proj-lhc-optics-web.web.cern.ch/proj-lhc-optics-web/OpticsSourceAllVersions.link/HELHC/V0.2/

(b) Assuming the bending radius is about 3 km and the magnets can go up to fields of 16 T, calculate the maximum energy the *HE-LHC* could accelerate protons to. At such high energy, even protons emit synchrotron radiation. Revisiting the synchrotron radiation lectures, what is the typical photon energy emitted by the protons and how much energy is lost per turn due to synchrotron radiation? Discuss the limitations and issues arising from synchrotron radiation emission.

(c) The *LHC* (and *HE-LHC*) design has 8 arcs and 8 straight sections. Alternatively, one could consider a racetrack design that has two very long arcs and two long straight sections, while retaining 4 interaction points. Outline what you think are the advantages and disadvantages to each approach.

For clarification do not hesitate to contact Suzie Sheehy (suzie.sheehy@physics.ox.ac.uk) and Leon van Riesen-Haupt (leon.vanriesen-haupt@keble.ox.ac.uk).

Question 5.3 (The Cavities)

It has been suggested that the *HE-LHC* could use an RF system similar to the one used in the LHC, but capable of providing a higher voltage.

(a) Revisit the lectures on RF cavity design and modelling and look in particular at the slides showing the pillbox and the elliptical-type cavities. Considering an RF frequency of 400.8 MHz (LHC frequency), estimate analytically the dimensions of a pillbox cavity at this frequency. Model this cavity in Superfish and plot the on-axis electric field. Comment on the suitability of such a cavity for *HE-LHC*. Start from the examples given in the tutorial.

(b) Assuming an accelerating field gradient of 5 MV/m and a relativistic beta of unity, model a single-cell elliptical cavity at 400.8 MHz. What is the Q of this cavity? Plot the on-axis electric field. To keep the synchrotron tune approximately the same as for the present *LHC* a voltage of 32 MV per turn is required. How many such cavities would be needed to provide this voltage? 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 on-axis electric field. 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, add the "NumberOfCells" keyword to the single cell model and use the "ELLCAV.EXE" solver. Start from the examples given in the tutorial.

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