Accelerator Physics Exercises No. 1

- Work to be handed in on 26 January 2023

The aim of Hilary Term's work is to prepare a Student Design Project on the study of the Future Circular Collider electron-positron (*FCC-ee*) particle physics research facility.

The Student Design Project relates to a novel research infrastructure based on a highest-luminosity energy frontier electron-positron collider (*FCC-ee*) to address the open questions of modern particle physics. It will be a general instrument for the continued in-depth exploration of nature at the smallest scales, optimised to measure precisely the properties of the Higgs boson at the percent level, as well as the Z and W bosons, the top quark and the Higgs coupling to the Z at the per-mille level.

The Student Design Project will concentrate on the *FCC-ee* and the investigation of the positron damping ring (pDR), focusing on the general lay-out, the lattice design, the choice of magnet technology and magnet design, and the RF system.

General information on the FCC is available at

https://fcc-cdr.web.cern.ch/.

A detailed description of the *FCC-ee* is available in the Conceptual Design Report (and references therein) at

https://fcc-cdr.web.cern.ch/

and under Tutorial 2 (Week 2) of this term at the course INDICO page at

https://indico.cern.ch/event/1230947/

Question 1.1 (Introduction)

Imagine you are writing the introductory section of the *FCC-ee* Design Report. Describe clearly and in detail the following:

(a) The physics that can be addressed by the *FCC-ee* as well as by the FCC hadron-hadron (*FCC-hh)* and FCC hadron-electron (*FCC-he)* colliders. Elaborate by discussing some key physics channels.

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

(c) At the high energies of the *FCC-ee*, electrons emit significant synchrotron radiation. Revisiting the synchrotron radiation lectures, what is the typical photon energy emitted by the electrons and how much energy is lost per turn due to synchrotron radiation for each of the *FCC-ee* operating beam energies?

(d) Describe the FCC-ee pre-injector complex. Elaborate on the reference design of the pDR and its role for the *FCC-ee*.

(e) Discuss the advantages and disadvantages of the FCC-*ee* compared to a Muon Collider, a Linear Collider, namely the Compact Linear Collider (CLIC) and the International Linear Collider (ILC), and the Circular Electron-Positron Collider (CEPC).

Question 1.2 (The Lattice)

Using the MAD-X input files available under Tutorial 2 (Week 2) of this term perform the following studies.

a) Reproduce the lay-out of the full pDR lattice and describe in detail the configuration of the two straight sections.

b) Calculate and plot the beam envelopes and optical functions of the pDR.

c) Plot and describe the lattice of the positron transfer line from the pDR to the Common Linac.

For any clarification, please contact Prof. Emmanuel Tsesmelis (Emmanuel.Tsesmelis@cern.ch).

Question 1.3 (The RF Cavities)

Referring to the Conceptual Design Report and Lectures 17-20 from last term at the course INDICO site, elaborate on the following points for the *FCC-ee* pDR RF system.

a) Examine and present the main requirements of the RF system for the pDR. Propose a normal-conducting or super-conducting RF system. Discuss the reasoning behind your choice.

b) Discuss the various possible RF frequencies for the pDR and the preferred choice of frequency. Can a single RF system be designed to meet the requirements for all *FCC-ee* collider energy cases?

c) Using the pDR parameters examined above, propose a single-cell superconducting elliptical-type cavity design at the correct frequency and model it using the Superfish software (including tuning it to the correct frequency). Assume an accelerating gradient of 5 MV/m.

d) Starting from the single-cell design, propose and model a multi-cell cavity. How many cells did you choose and why? Estimate how many cavities would be needed to provide the required accelerating voltage per turn. Estimate the total beamline space needed for the RF system. Present your cavity design, the main parameters and the field on axis. (Hint: Superfish examples are a good starting point).

For any clarification, please contact Dr. Ciprian Plostinar (ciprian.plostinar@ess.eu).

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