Thesis Abstract

Rasha ABUKESHEK

Title: Magnetic Design and Beam Optics Optimization for PERLE (Powerful Energy Recovery LINAC for Experiments)

Abstract: PERLE (Powerful Energy Recovery LINAC for Experiment) is a high-power energy recovery linac (ERL) project based on superconducting RF technology, hosted at the Irène Joliot-Curie Laboratory of Physics of the Two Infinities (IJCLab) in Orsay. It accelerates electrons with a beam current of 20 mA up to an energy of 250 MeV, through three accelerating passes followed by three decelerating passes.

PERLE serves as a validation platform for the development of ERL technology, in preparation for future accelerators pushing the frontiers of energy and intensity. Due to its beam parameters and specific design challenges, it represents a unique testbed for demonstrating multi-turn, high-current ERL operation, as required for the LHeC project. PERLE could also be considered as a test facility for Future Accelerator and System, aimed at improving their energy efficiency, and in particular for validating and testing the 800-MHz cryomodules for the FCC. It will also host experiments such as inverse Compton scattering for X-ray production and electron–nucleus (eN) scattering for nuclear physics research.

The main part of this thesis is devoted to the design of PERLE’s magnetic elements, namely dipoles and quadrupoles. The design was carried out using the finite element method with the OPERA-3D code, optimizing the geometries to meet beam dynamics requirements while complying with spatial integration and vacuum chamber constraints. For the dipoles, the focus is on achieving the required bending field and ensuring field uniformity. For the quadrupoles, the goal is to reach the specified gradient with sufficient field quality and adequate aperture.

Magnetic field calculations make it possible to evaluate the effective length, multipole content, and particle trajectories, thereby ensuring proper beam transport throughout the lattice.

The second part of the thesis addresses the effect of linear lattice imperfections. Misalignments of the quadrupoles and their impact on the beam are analyzed. In particular, transverse quadrupole misalignments are studied, modeled as a normal distribution with a standard deviation of 100 µm. The effect of these misalignments on the beam orbit is used to identify strategic locations for the installation of beam position monitors (BPMs). Magnetic correctors are then integrated into the lattice near the BPMs to compensate for these misalignments. Finally, the BMAD code optimizer is employed to determine the optimal correction strategy as well as the required range of correction strengths.