Design of Electron Storage and Damping Rings

Instructors:
Andy Wolski and David Newton, University of Liverpool/Cockcroft Institute

Purpose and Audience

The purpose of this course is to introduce the students to the design and physics issues of electron (or positron) storage rings and damping rings, with emphasis on beam dynamics. This course is suitable for anyone who has a basic understanding of the principle of charged particle optics, and who also has an interest in electron storage rings.
Prerequisites: Fundamentals of Accelerator Physics.

Objectives

By the end of the course, students should be able to:

- explain the physical principles governing beam properties and behavior in electron storage rings;
- explain the issues involved in optimization of values for the circumference, beam energy, and other parameters for storage and damping rings for various applications;
- explain the physics behind potentially limiting beam dynamics effects (including acceptance, beam lifetime, and instabilities), and perform initial assessments of their likely impact in a given design;
- describe techniques used to mitigate potential performance limitations;
- outline the requirements for key technical subsystems, including the injection system, magnets, RF, vacuum system, and insertion devices.

Instructional Method

There will be nine lectures over five mornings. Afternoon sessions will be used for discussion and for working through and reviewing set problems. There will be homework and a final examination.

Course Content

The physical principles behind the design and operation of electron (and positron) storage and damping rings will be described, including relevant aspects of charged particle optics and beam dynamics with synchrotron radiation. Expressions for the equilibrium beam properties, depending on the lattice structure, will be derived, and applied to the design of storage rings for particular applications, including colliders and light sources. Beam dynamics problems related to single-particle dynamics (including dynamic aperture and acceptance, coupling correction) and collective effects (such as microwave instability, resistive-wall instability, Touschek scattering, electron cloud and ion effects) will be discussed. The requirements for some of the technical subsystems, including the injection components, magnets, RF, and vacuum system, will be considered in the context of their impact on beam behavior and the performance of the storage ring.

Credit Requirements

Students will be evaluated based on performance in the final exam (50% of final grade), and the homework assignments (50% of final grade).

Outline of Lecture Contents

Lecture 1: Review of Linear Beam Dynamics

- Optical functions (beta function, dispersion)
- Momentum compaction
- Emittance, energy spread, bunch length
- Synchrotron radiation: energy loss and damping times
- Quantum excitation: equilibrium emittance, energy spread, bunch length

Lecture 2: Lattice Design I: Linear Dynamics

- Optical functions and lattice parameters as a function of cell design
- Lattice styles: FODO, DBA, TBA and TME lattices

Lecture 3: Lattice Design II: Nonlinear Dynamics

- Chromaticity and chromatic correction
- Dynamic aperture and energy acceptance
- Energy acceptance

Lecture 4: Insertion Devices

- Use of undulators and wigglers for enhancing the production of synchrotron radiation
- Impact of insertion devices on radiation damping and equilibrium beam sizes
- Nonlinear effects of undulator and wiggler fields

Lecture 5: Coupling and Alignment

- Fundamental lower limit on vertical emittance from synchrotron radiation
- Generation of vertical emittance from coupling and dispersion
- Coupling and dispersion generated by alignment errors
- Sensitivity to (and correction of) effects of magnet vibration and ground motion

Lecture 6: Classical Coupled-Bunch Instabilities

- Wake fields and impedances
- Resistive-wall wake fields and higher-order modes
- Dynamics with long-range wake fields
- Resistive-wall instability growth rates
- Bunch-by-bunch feedback systems

Lecture 7: Space-charge, Intrabeam Scattering and Touschek Effects

- Space charge
- Intrabeam scattering
- Touschek lifetime

Lecture 8: Classical Single-Bunch Instabilities

- Short-range wakefields
- Potential-well distortion
- Microwave instability threshold
- Keil-Schnell-Boussard criterion
- Transverse mode coupling instability

Lecture 9: Synchrotron Light Sources

- Key parameters and performance metrics
- Choice of accelerator parameters
- General design issues