Fourth International Accelerator School for Linear Colliders

Syllabus of Elective Courses

September 7-18, 2009

Jixian Villa, Huairou, Beijing, China

<u>Course A: Accelerator Physics</u>

Lecture A1: Linac (12 hrs)
Daniel Schulte, CERN

1. Joint Session of Courses A & B: (3 hrs)
   One of the most fundamental choices for a future linear collider is the choice of the acceleration technology in the main linac. The lecture will introduce into the beam dynamics issues of this area and how they are driven by the acceleration technology. The design of the main linacs of ILC and CLIC will be presented. The effect will be discussed of single and multi bunch wakefields in the transverse and longitudinal plane. It will be illustrated how the mitigation of the wakefield introduces other beam dynamics problems like dispersion. A short introduction into the process of parameter optimisation will be given using the example of CLIC.

2. Accelerator Physic Session: (9 hrs)
   The lecture will deepen the discussion of the main linac beam dynamics issues and extend it into a more quantitative regime. The design of the lattice and its optimisation will be investigated. The origin of static imperfections will be discussed and the correction techniques that can be used to mitigate their effect will be studied in detail. Particular emphasis will be on the beam-based alignment algorithms. Analytical and numerical tools to make quantitative predictions of the beam performance will presented. Similarly, the origin of dynamic imperfections and the mitigation strategies will be discussed. In particular, the design and performance of beam-based feedback will be detailed.

Lecture A2: Sources (6 hrs)
Masao Kuriki, Hiroshima University/KEK

The lecture consists of two main parts: electron source and positron source. For each part, fundamental process of particle generation, forming a bunched beam, general concept of particle sources and its adaptations for ILC and CLIC are explained. Various concepts, not only the baseline scheme, but also advanced alternative schemes, are explained.

A good text book for the particle sources of linear colliders does not exist. Corresponding chapters in accelerator part of RDR (Reference Design Report of ILC <u>http://www.linearcollider.org/cms/?pid=1000025</u>) is a good reference.

Lecture A3: Beam Delivery Systems and Beam-Beam (6 hrs)
Olivier Napoly, Saclay

Part 1 (3 hrs)

- Introduction to BDS (30')
  - Functionalities and ILC BDS designs
- Beam transport basics (1h30')
  - Beam matrix:
    - Emittance
    - Beta and correlation functions
    - Normal coordinates
  - Luminosity:
    - Lorentz invariance
    - Impact of errors
    - Crossing angle and crab crossing
  - Linear optics:
    - Twiss and dispersion functions
    - Beam invariants and beam matching
    - Aberrations and chromatic correction
  - Emittance growth effects:
    - Chromatic and wakefield effects
    - Alignment tolerances
- Final doublet (30')
  - Low-beta scaling laws
  - Superconducting quadrupole design
  - Tolerances and field harmonics
- Synchrotron Radiation (30')
  - Emittance growth
  - Oide effect

Part 2 (3 hrs)

- Collimation (30')
  - Collimation requirements
  - Collimation section
  - Betatron and energy collimation
- Detector Solenoid (30')
  - Solenoid designs
  - Solenoid effect on beam
  - Correction methods
- Beam-beam effects (30')
  - Beam-beam deflection and pinch effect
  - Beamstrahlung
  - Pair production
- Luminosity optimisation (30')
  - BDS tuning knobs
  - Fast feedback system
  - Luminosity tuning
- Beam extraction (30')
  - Beam loss management
  - Beam dump principles
- Conclusion (30')

- SLC experience
- BDS test facilities

Lecture A4: Damping Rings (12 hrs)
Andy Wolski, University of Liverpool/Cockcroft Institute

1. Purpose and Audience:
   The purpose of this course is to introduce the students to the design and physics issues of linear collider damping rings, with emphasis on beam dynamics. Graduate level knowledge of electromagnetism, special relativity and (classical) mechanics is assumed. Early lectures will review basic principles of particle dynamics in accelerators and storage rings, but students will probably find it helpful to have some prior knowledge of these topics.

2. Objectives:
   By the end of the course, students should be able to:
   - describe the performance requirements of linear collider damping rings;
   - explain the issues involved in optimization of values for the circumference, beam energy, and other parameters, and explain how the parameters for the ILC damping rings (for example) have been arrived at;
   - explain the physics behind potentially limiting beam dynamics effects, including acceptance, vertical emittance, microwave instability, resistive-wall instability, intrabeam scattering, electron cloud effects and ion effects;
   - perform initial assessments of the likely impact of certain potentially limiting effects, stating the relevant assumptions;
   - describe the features and requirements for key technical subsystems, including the injection/extraction kickers, vacuum system, and the damping wigglers.

3. Instructional Method:
   There will be eight lectures (see outline below), of approximately 1½ hours each. Problems will be set for homework; solutions to the problems will be explained in tutorials.

4. Course Content:
   The performance requirements of linear collider damping rings will be explored, and appropriate parameter regimes considered. Beam dynamics problems related to single-particle dynamics (dynamic aperture and acceptance, low-emittance tuning) and collective effects (microwave instability, resistive-wall instability, space-charge tune shifts, intrabeam scattering, electron cloud and ion effects) will be discussed. The requirements for some of the technical subsystems, including the injection/extraction kickers and the damping wigglers, will be considered in the context of present capabilities.

5. Outline of Lecture Contents:
   A4.1: Introduction to Damping Rings
   - Role of the damping rings in a linear collider
   - Principles of operation and overall structure
   - Parameter and design constraints
   - Injection and extraction

   A4.2: Review of Linear Beam Dynamics and Radiation Damping

- 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

A4.3: Lattice Design

- Optical functions and lattice parameters as a function of cell design
- Lattice styles: FODO, DBA and TME lattices
- Chromaticity and chromatic correction
- Insertions: wiggler; injection/extraction

A4.4: Damping Wiggler and Nonlinear Dynamics

- Use of wigglers to enhance radiation damping
- Impact of wigglers on equilibrium beam sizes
- Nonlinear effects of wiggler fields
- Analysis methods for nonlinear dynamics

A4.5: 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
- Effects of magnet vibration
- Effects of ground motion

A4.6: 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

A4.7: Classical Single-Bunch Instabilities

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

A4.8: Other Collective Effects

- Space charge
- Intrabeam scattering
- Touschek effect
- Electron cloud effects
- Techniques for suppressing electron cloud
- Ion effects

Course B: RF Technology

Lecture B1: Room Temperature RF (12 hrs)

Sami Tantawi, SLAC

This course introduces microwave/RF components and systems for high gradient linear accelerators. This course is suitable for advanced undergraduate students and entry-level graduate students who are considering accelerator physics as a possible career and for engineers and operators who want to learn more about microwave systems and design and characterization techniques for linear accelerators and associated components. First, we will discuss circuit repetitions and transmission line theory. We then discuss solutions of Maxwell equations to guided electromagnetic fields. This will be followed by exposition to representation theory for microwave circuits and elements. These representations will be applied to accelerator structures and systems. We then move to perturbation theory and variational techniques and expose them by practical applications for microwave measurement techniques. We end up by introducing pulse compression systems and RF sources.

1. Transmission Line Theory
    a) Circuit Theory and representation waveguide and transmission lines
    b) Impedance, group and phase velocities
    c) Representation on the complex reflection coefficient plane
    d) Resonant cavities
    e) Matching and impedance transformations
2. Guided Electromagnetic Wave
    a) Maxwell equations
    b) TEM transmission lines
    c) Waveguides
3. Microwave Junction Representations
    a) Reciprocity
    b) Impedance matrix representations
    c) Scattering matrix
    d) General representations of N- port junctions and symmetry groups
    e) The synthesis problem
    f) Periodic structures
4. Measurements
    a) Perturbation theory
    b) Variational techniques
5. Applications
    a) Resonant cavities and time domain response
    b) Pulse compression systems
    c) RF sources

Lecture B2: Superconducting RF (12 hrs)

Kenji Saito, KE /Tokyo University (ICEP)

Superconducting RF cavity is a core technology for the ILC. The object of this course is to learn about SRF cavity from mainly its design and fabrication to testing based on science and technology point of views. At the first, superconductivity basics are lectured for the SRF application. Currently, niobium is the best material for SRF cavity. The material production in companies is introduced on high purity niobium. We will then come to cavity design concept. Here, the lecture will emphasize the RF basics for students who are not familiar to microwave.

You will learn a very exciting application of electromagnetic theory starting from Maxwell equations. Cavity auxiliaries like high power coupler, Lorentz detuning compensation tuner, which are very important for beam acceleration, also will be discussed. For accelerator machine construction cavity integration is a very important issue. For many audiences, cryomodule or cryogenics will be not so familiar. They are very much engineering and briefly discussed. Then, we will see the real cavity fabrication technologies. Various cavity performance limitations and the cures are discussed with surface preparation techniques. We will learn how to measure the SRF cavity performance precisely. At the last, we will see the current R&D status of high gradient SRF cavity for ILC.

1. SRF Basics
    - Superconductivity Basics for SRF application
    - Niobium Material Production
2. Design Concept for SRF Cavity and Auxiliaries
    - SRF Cavity Design
    - HOM Issues
    - Lorentz Detuning
    - RF Input Coupler
    - Cavity Pre-tuning
3. SRF Cavity Integration and Cryogenics
    - Cavity Dressing
    - Cryomodule
    - Cryogenics
4. SRF Cavity Fabrication and Testing
    - Cavity Fabrication
    - Cavity Performance Limitations and the Cures
    - Surface Preparation
    - Cavity Performance Measurement
5. SRF Cavity R&D for the ILC

Lecture B3: LLRF and High Power RF (9 hrs)
Stefan Simrock and Zheqiao Geng, DESY

1. Audience:
   This course is intended for accelerator physicists, engineers and students with some familiarity with accelerator technology, electronics systems, and basic mathematical knowledge.

2. Objectives:
   The students will gain an understanding of the various aspects of RF Systems beginning with the basic concepts for high power rf generation and the control of cavity field in presence of field perturbations. State-of-the-art hardware and applications software will be presented.

3. Course Syllabus:
   Starting with a short description of the components of an rf system the requirements for field control and high power generation will be presented. Sources for field perturbations such as microphonics, Lorentz force detuning and beam loading will be discussed. This will be followed by a general introduction to control theory as a prerequisite for the understanding of field control and resonance control

B3.0. Introduction to RF Systems
   a) Concept of High Power RF System
   b) Concept of Low Level RF System

B3.1. Introduction to control theory

B3.2. LLRF Systems
   a) Requirements for LLRF control
   b) Source of field perturbations
   c) Cavity field control
   d) Cavity resonance control
   e) LLRF Hardware
   f) LLRF Control applications

B3.3. High Power RF
   a) Klystron
   b) High voltage modulator
   c) RF power distribution

B3.4. Other topics (if time permits):
   a) Timing and Synchronization
   b) Beam feedbacks
   c) Introduction to requirements engineering

4. Reading Assignments:
   See Control Theory and Math lectures from CERN School on Digital Signal Processing at http://cas.web.cern.ch/cas/Sweden-2007/Lectures/Sigtuna-lectures.htm <https://owa.desy.de/exchweb/bin/redir.asp?URL=http://cas.web.cern.ch/cas/Sweden-2007/Lectures/Sigtuna-lectures.htm>
   and LLRF and High Power RF lectures from previous LC Schools
   http://www.linearcollider.org/cms/?pid=1000401
   <https://owa.desy.de/exchweb/bin/redir.asp?URL=http://www.linearcollider.org/cms/?pid=1000401>