*US Particle Accelerator School/Duke University*

***Course Descriptions***

Introduction to Accelerator Physics I & II
3 Semester Hours
Stephen D. Holmes - Fermilab

This course will present an introduction to the operating principles and performance limitations of particle accelerators. Representative topics to be covered include: historical development of particle accelerators, single particle transverse and longitudinal motion, beam emittance, collective effects, resonance and other non-linear effects, effects of magnetic imperfections, beam diagnostic devices, synchrotron radiation, and accelerator design strategies. A working knowledge of classical mechanics and electromagnetism is required.

Accelerator Mathematics I & II
3 Semester Hours
Richard M. Talman - Cornell University

A course emphasizing the mathematics of accelerators and practical calculations needed to design them and to understand their performance. Mathematical topics include matrices, nonlinear maps, differential and difference equations, Hamiltonian formulation, distribution functions, Fourier and Laplace transforms, nonlinear oscillators, and perturbation theory. Accelerator topics will be drawn from design of idealized models, linear and nonlinear particle motion, feedback, instabilities, and diagnostic procedures such as signal processing, spectral analysis and beam transfer functions. The "physics" of practical computer codes will be described, but the required course work can be adequately done with programmable hand calculators.

**Week One**

Introduction to Linear Accelerators
1-1/2 Semester Hours
Thomas P. Wangler and James H. Billen - Los Alamos National Lab

This introduction to rf linear accelerators will treat rf accelerating structures and linac beam dynamics. The emphasis will be on the underlying principles. Topics will include traveling-wave and standing-wave acceleration, slow-wave and periodic structures, normal-mode characteristics of coupled cavities, dispersion curves, and cavity figures of merit such as transit-time factor and shunt impedance. The principles of operation of the most common linear accelerating structures will be presented, including the drift-tube linac, coupled-cavity linacs, the iris-loaded structure, and the radiofrequency quadrupole. We will treat focusing and defocusing effects in a linac, and the longitudinal and transverse beam dynamics for both noninteracting particles and high-intensity beams. We will discuss such topics as emittance growth, space-charge effects, and wake fields, all of which are important in modern high-intensity linacs. Prerequisites: classical mechanics and electromagnetism.

Control Theory with Applications to Accelerators
1-1/2 Semester Hours
John D. Fox and Haitham Hindi - Stanford Linear Accel. Center

Many next generation particle accelerators and storage rings propose the use of feedback systems to suppress multi-bunch instabilities. The design and operation of these systems present many opportunities to exploit well-developed techniques from control theory. This class provides an introduction to modern control concepts, particularly state space descriptions of accelerator dynamics, and illustrates the formal design of feedback controllers. The class covers both continuous and discrete-time controllers, transformations between state space and frequency domain system descriptions, and introduces the use of system estimators and observers via Kalman filters and LQG (linear quadratic gaussian) optimal state feedback. Applications of these techniques are illustrated via examples of feedback controllers applied to multi-bunch instabilities and RF impedance control in accelerators. The class will include the use of computer simulation models to allow hands-on experience with selected applications.

Introduction to High Current Beam Transport
1-1/2 Semester Hours
George J. Caporaso and Yu-Jiuan Chen, Lawrence Livermore Lab

Introduction: applications of high current beams. Transport limits: beam envelope equations and dynamics. Discussion of various focusing systems: continuous and alternating solenoids, quadrupoles, foils, ion channels, resistive wires and magnetic multipole arrays. Introduction to transport instabilities: cumulative beam breakup, transverse resistive wall, transverse ion-hose, longitudinal instability of a heavy ion beam; effects of phase mix damping. Parametric instabilities and beam halo formation. Prerequisites: electromagnetism and classical mechanics.

Introduction to Accelerator Applications
1-1/2 Semester Hours
Robert A. Jameson, Los Alamos National Lab, George H. Gillespie, G.H. Gillespie Assoc., Inc., & Jose Alonso, Lawrence Berkeley Lab

Particle accelerators are being widely used, and proposed new applications are expanding in industrial and medical areas, for major societal options in energy production and waste management, and for research. Scoping and optimization for applications require both broad and deep understanding of all accelerator and beam delivery system aspects and translation of the customer requirements. The course will provide an introduction to the variety of accelerator applications, the required performance specifications, the characteristics and constraints of various accelerator systems, methods for system optimization, and major cost, technical and performance tradeoffs that must be considered. System definition and optimization software will be used to lay out representative linear accelerator systems and study the effects of constraints and tradeoffs. The codes operate on Macintosh computers. Students should have some familiarity with introductory accelerator physics and engineering. Code: Accelerator System Model, G.H. Gillespie Associates, Inc. Textbook: Principles of Charged Particle Acceleration, S. Humphries, Jr., J. Wiley & Sons publishers.

## Week Two

Introduction to RF Systems
1-1/2 Semester Hours
David P. McGinnis and Robert C. Webber - Fermilab

This course is designed to give an introduction to both the physics of Longitudinal Beam Dynamics and the important engineering aspects of RF Accelerating Systems. The concepts of phase focusing, longitudinal phase space and emittance, bucket area, transition, synchro-betatron coupling, and beam loading will be presented and quantified. Engineering concepts of frequency domain analysis, RF signal processing, RF power transmission, accelerating cavity design, and low level RF beam control will be included. Practical designs and considerations of accelerating cavities, high power RF systems, and RF control will be described. The course will emphasize physical concepts and engineering and problems will be selected primarily from proton synchrotrons and storage rings. Prerequisites: familiarity with introductory accelerator physics and basic electricity and magnetism.

Numerical Methods for Charged Particle Beams
1-1/2 Semester Hours
Stanley Humphries, Jr. - University of New Mexico

The course addresses numerical solutions for static and dynamic electric/magnetic fields and applications to self-consistent charged-particle dynamics. The goal is to provide hands-on knowledge that allows students to build their own numerical applications and to use available codes effectively. There will be a detailed exposition of the finite difference and finite element methods. These are applied to electrostatic fields with space-charge, magnetostatic fields with non-linear materials, and electromagnetic fields in two and three dimensions. The course reviews numerical computations of particle orbits and assignment of charge and current density. Extensive material is presented on the design of electron and ion guns using the ray tracing technique. The course describes the Particle-in-Cell method for calculations of short-pulse beams and instabilities. There is also a review of a variety of essential numerical techniques including the Fast Fourier Transform, least-squares fits, interpolation and numerical solutions to ordinary and partial differential equations. Prerequisites: Basic knowledge of undergraduate electricity and magnetism, facility in Fortran, Pascal or C. Recommended texts: M.N.O. Sadiku, Numerical Techniques in Electromagnetics (CRC Press, Boca Raton, 1992); W.H. Press, S.A. Teukolsky, W.T. Vettering, B.P. Flannery, Numerical Recipes in Fortran (Cambridge University Press, Cambridge, 1992) or any other edition in Pascal or C.

Magnetic Systems
1-1/2 Semester Hours
Klaus Halbach, Ross Schlueter & Jack Tanabe, LBL

Beginning with a review of Maxwell's Equations, this course introduces the fundamentals of the design of electromagnets, pure permanent magnets, and hybrid iron/permagnet magnet systems. Topics covered include (1) theory of a function of a complex variable and its relationship to magnetic design, (2) analytical representations of permanent magnet systems, (3) hybrid system theory, (4) conformal mapping for magnet design, (5) Schwarz-Christoffel technique and applications, (6) design of magnets for accelerator rings, (7) specialty magnets, (8) pure permanent magnet/hybrid magnets/electromagnet insertion devices, (9) eddy current effects, (10) field perturbations and their propagation, (11) magnetic forces, (12) coil construction and cooling, and (13) magnet design economics.

Introduction to Radiation Physics
1-1/2 Semester Hours
J. Donald Cossairt, Fermilab and Jeffrey Stapleton, CEBAF

Radiation physics for personnel and environmental protection at accelerators will be studied in this course. The composition of accelerator radiation fields for electron, proton and ion accelerators at all energies will be reviewed extensively. Building upon this basic information, the methods of designing radiation shielding at accelerators will be presented. Specific attention will be devoted to low-energy neutron phenomena which are found at nearly all accelerators. The production of induced radioactivity in both accelerator components and environmental media will be discussed in detail. A discussion of radiation detection instrumentation which has been found to be particularly useful in understanding accelerator radiation fields will be included. Finally, a synopsis of the program elements of a successful accelerator radiation protection program will be given. The problems which accompany the course are designed to promote understanding of the theoretical material, foster the ability to solve problems related to accelerator radiation physics, and lead to an intuitive comprehension of radiation physics at accelerators. Participants in the course are expected to have a basic undergraduate background in physical science and a mathematical background at the level of first-year undergraduate calculus.