Fundamentals of Proton Linear Accelerators with Simulation Lab

John Staples, LBNL

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Old Dominion University

Instructors:

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George Gillespie, GHGA,

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Purpose and Audience

This course is aimed at accelerator physicists, engineers and technicians who want to learn the physics of low-energy linear accelerators (linacs) and the use of widely-available software to design and optimize transport systems and accelerators. Prerequisites: undergraduate electricity and magnetism course, undergraduate mechanics course, calculus through differential equations, familiarity with computers.

Objectives

The course will focus on the fundamental principles of acceleration and particle transport. Enough accelerator theory will be presented to establish a solid groundwork of understanding, and the students will participate in the design of several examples of accelerator systems.

Instructional Method

The course will combine lectures with a team approach involving the students. Morning lectures will be followed by the students forming several teams, each of which will work together, using computers loaded with appropriate software to work through the design of an accelerator or transport system that will satisfy a given set of requirements. The course will have three instructors who will interact with the teams, and it is expected that each team member will actively teach the others in the computer lab part of the course. The students will be expected to interact highly with the instructor during the lecture part of the course.

Course Content

The lectures will cover the physics of RF linear accelerators for protons including the use of popular computer codes to design and optimize simple beam transport systems, drift-tube linacs and radio-frequency quadrupole (RFQ) accelerators. The course will cover basic beam transport theory including the description of beams, beam transport and collective effects and how to apply codes such as Transport, Turtle and Trace-3D. The beam dynamics of low-energy linacs will be covered and example accelerators will be designed by the students using codes such as Parmila for drift-tube accelerators and Parmteq for RFQ accelerators. The course will also include basic electromagnetics design of low-energy linac cavities, using 2-D simulation codes such as Superfish, as well as the basic design of magnetic and electrostatic beam transport elements. Afternoon laboratory sessions apply the subject matter in the lectures to the design of accelerator examples.

Reading Requirements

The recommended text is “RF Linear Accelerators” by Thomas Wangler, Wiley & Sons publishers (to be provided by the USPAS). The material in the textbook will be covered in a non-linear method, and will be accompanied by extra material written by the instructors, covering both accelerator theory and support information for the computer codes used in the course.

Credit Requirements

Students will be evaluated based on their performance: 35% homework, 35% computer lab sessions and 30% final exam.

Goals of the Course

Get a basic knowledge of hadron linacs and beams

Get experience with most common computer codes

Get knowledge of additional references to continue

Less emphasis on theory, more emphasis on practical accelerator modeling, the way it's actually done

In this course you will learn

Physics of Beams

- Electromagnetic units
- Description of beam parameters: emittance, Twiss parameters
- Interaction of beams with external fields
- Interaction of beam with themselves: space charge

Beam Transport

- Beam transport elements: bends, focusing devices
- Periodic transverse focusing lattices

Acceleration

- Beam bunching
- Longitudinal focusing

Accelerator Structures

- Sloan-Lawrence and Alvarez structures
- Radio Frequency Quadrupole structures
- Rebunching cavities
- Beam dynamics in accelerators

Design of Accelerator Structures

Superfish calculation of structure components
Assembly of components into an accelerator

Beam simulation

Generation of a beam ensemble
Transport of beam bunch through accelerator
Analyze beam quality
Optimize accelerator design

Beam Matching

Design transport systems between RFQ, DTL and SCL structures
Include beam space charge

Teams will present complete accelerator systems design at end of course

Course Outline

Beam Physics

Introduction, get acquainted with the computers, form teams
Definitions
Beam Transport
Focusing and Transport
Collective Effects
Beam Dynamics in a gap

Overview of computer lab and PBO Lab Software
Set up simple beam line simulation

Fundamental of Linac Beam Physics

Resonant cavities, cavity modes
Groups of cavities, matching into cavity
Longitudinal focusing, buncher cavities

Overview of codes Parmila and Turtle
Simulate FODO lattice, buncher simulation, space charge

Computational Electromagnetic Structure Modeling

Superfish example of a buncher cavity
Superfish modeling of a DTL cell
Drive loop, cavity Q
Superfish modeling of RFQ quadrant
Drift-tube linac design with Parmila
Beam transport modeling with Parmila and other codes

RFQs

RFQ design theory: bunching, focusing stability
Introduction to Parmteq
Detailed RFQ design example

Matching

Transport modeling with Trace 3-D, Parmila
Design matching transport lines between accelerators

Final Exam

Teams will present complete accelerator systems

Course Structure

Lectures in the mornings
Computer interaction in the afternoons
Homework to be turned in the next morning
Final exam the last day

Students will form several problem-solving teams
The course will be highly interactive between the instructors and students

Supplementary Materials

Staples: RFQ's – An Introduction: pdf file, obtainable from the author
Staples: USPAS lecture notes for this course: several pdf files

Some useful web sites:

JACOW:	accelconf.web.cern.ch/AccelConf	Past Accelerator Conferences
PRSTAB:	prst-ab.aps.org/Search	Open, refereed accelerator papers
LAACG:	laacg1.lanl.gov	(Requires registration)

Two books by Stan Humphries: primarily devoted to pulsed-power machines but very good treatment of beam physics. Stan allows single downloads of his books, but requires permission to distribute multiple copies.

http://www.fieldp.com/cpa/cpa.html
http://www.fieldp.com/cpb/cpb.html

For more general information, but surprisingly useful:

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
http://en.wikipedia.org/wiki/Main_Page

John Staples, LBNL

Ph.D., experimental nuclear physics, U of Illinois

Accelerators since 1968, LBNL since 1971

Designed and commissioned:

- 5 RFQs
- 2 Drift-tube Linacs
- 1 Heavy-Ion Wideroe
- Superconducting electron accelerator
- Many beam lines

Current interests:

- Fiber optics-based femtosecond timing systems
- High pulse rate photoinjectors

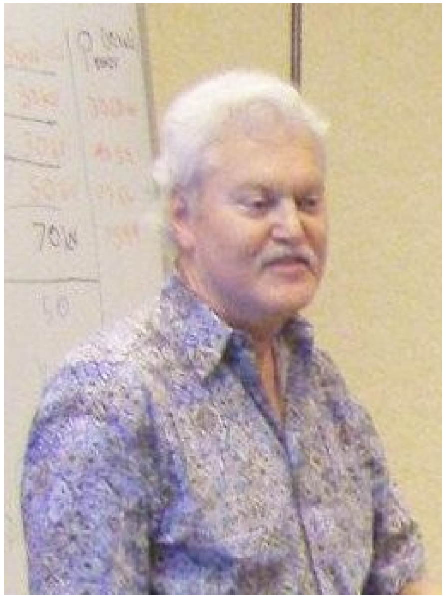
Long career in almost all aspects of accelerators and their use.

Years of experience as consultant to government and technical industries.
Fellow, American Physical Society

George Gillespie, GHGA

Ph.D., Nuclear Physics

Founder and President,
G. H. Gillespie Associates, San Diego



GHGA began operations as a sole proprietorship in 1988 and following two years of successful growth the Company was incorporated in the State of California in 1990. From 1988-1993 the primary business line involved conducting assessment studies and performing other technical analyses on a variety of practical applications of particle accelerators for U. S. Government agencies and their prime contractors. An extensive software capability was developed within the firm as a part of those activities. In 1992, the Company began marketing a line of scientific software for use at university, industrial and government laboratories. The success of that product line resulted in the award of several contracts for the development of custom scientific and educational software applications. Since 1994 GHGA has concentrated on the development of custom and prepackaged software, with innovative graphic user interfaces and data visualization tools for scientific and educational programs becoming the Company's signature business line. AccelSoft Inc. was formed in 1997 as a wholly owned subsidiary to publish, market and distribute the growing line of prepackaged software products.

Sang-ho Kim, SNS/ORNL

Ph. D., nuclear fusion, plasma and accelerator at Nuclear Engineering Dept, Seoul National University

Accelerator since 1999

Experiences in design, commissioning and operation of;

- SNS Superconducting linac
- SC central model coil for fusion device
- many plasma/beam devices

Presently

- SNS SCL Area Manager
- Plasma processing for SRF cavities (alternative method)
- SNS power upgrade
- RFQ/Foil/DTL/LLRF/HPRF/other devices…

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5. **Accelerator Structures II – Multiple Cavity**
   Groups of cavities
   Dispersion diagram
   Drift-Tube Linac – Superfish
   Parmila calculation of beam dynamics
   Bead Pull and cavity tuning
   Transmission lines
   Coupling RF into cavity

6. **Beam dynamics III - Defocusing Effects**
   Transverse defocusing
   Collective Effects
   Trace 3D beam simulation

7. **Accelerator Structures III - (RFQs)**
   SNS Front End configuration
   RFQ – Transverse Beam Dynamics
   RFQ - Longitudinal Beam Dynamics
   RFQ structure calculation with Superfish
   Parmteq / Curli / Rfquick

8. **Beam matching with space charge**

9 **Accelerator Structures IV – Tuning and stabilization**
Tuning RFQ
RFQ Mode Stabilization

10. **Accelerator Structures V - Superconducting Linac**
(TBW)

11. **Design Project – Entire Front-End Design**
Design RFQ, DTL, SCL
Match Ion source through LEBT with space charge
Match RFQ to DTL, include bunchers with space charge
Match DTL to SCL

12. **Final Exam**
Group presentations of Front-End designs