

Preface

The motivation for writing “*Charged Particle Beam Physics: An Introduction for Physicists and Engineers*” is to simplify the process of learning accelerator physics. The book directly addresses the fundamental topics required in this field. Although my background is primarily in laboratories utilizing electrostatic and linear accelerators, this book also caters to circular accelerator laboratories, addressing common elements found across various accelerator systems. The beam optics examples provided focus on single-pass configurations and typically deal with standard beam transport lines.

This book represents the culmination of years of extensive research, reflection, and collaboration in accelerator physics. During this time, I had the privilege of visiting Fermilab, USA, and CERN, Geneva, where the insights gained from these experiences, have been invaluable. The process of writing this book has been both challenging and rewarding, prompting me to explore new perspectives and deepen my understanding of the subject.

Charged Particle Beam Physics: An Introduction for Physicists and Engineers is structured into eight chapters, each focusing on a key aspect of accelerator physics. I have incorporated beam optics code simulations to visually illustrate basic concepts in beam optics. Below is a summary of the chapters:

1. **Chapter 1:** Introduction to different types of accelerators and the historical evolution of accelerator technology.
2. **Chapter 2:** Basics of particle sources and their working principles.
3. **Chapter 3:** Fundamentals of beam optics and an introduction to phase space formalism.
4. **Chapter 4:** Motion of charged particles in various magnetic fields.
5. **Chapter 5:** Motion of charged particles in various electric fields.
6. **Chapter 6:** Motion of charged particles in radio frequency fields.
7. **Chapter 7:** Determining basic beam parameters using standard beam diagnostics utilized worldwide.
8. **Chapter 8:** Understanding vacuum systems in accelerators, covering vacuum physics, pumps, and gauges.

This book is grounded in my 18 years of experience at the Inter University Accelerator Center, New Delhi, where I have primarily focused on beam optics for designing particle accelerators. I have consistently enjoyed working on hands-on calculations and beam optics simulations using various simulation and tracking codes. Achieving accurate transverse

and longitudinal parameter matching for particle beams is a key part of designing effective particle accelerators. It requires careful estimation of beam matching parameters alongside the design parameters of beam optical devices. The conversion of effective beam optics layouts into their physical counterparts must be performed with precision to ensure that the accelerator functions as closely as possible to the ideal model.

The book is written in a broad, accessible format, intended to serve as a primary source and is mainly for undergraduate student to get quick access to the field and also extend the outreach to scientists and engineers worldwide. It is particularly useful for beginners in accelerator physics, providing a clear and concise introduction to key topics. Additionally, it can serve as a practical reference for those involved in designing accelerator components, providing quick insights and essential information before proceeding with computational simulations. The student working at school level in beamline project can quickly get familiar to fundamental concepts in accelerator physics.

Apart from basic physics to undergraduate students, the aim of this book is also to explore the design of accelerator machines and their basic components. The academic community working in accelerator physics often needs to perform fundamental calculations before embarking on detailed simulations, whether for beam optics or the design of beam optical devices. Based on my experience, I have compiled many of the essential elements of accelerator physics into a single resource, allowing students to easily grasp the basic principles. This book serves as both a detailed glossary of accelerator terms and a practical guide for performing the basic calculations associated with most of the accelerator elements.

The content covers electrostatic, magnetostatic, and radiofrequency devices used in accelerator physics, with an emphasis on both transverse and longitudinal beam dynamics. The introductory chapters provide a broad overview of the principles behind various particle accelerators and ion sources. Different types of ion sources are characterized by their beam emittance, current, and profiles, all of which present significant challenges for beam extraction and transport to the target. Accordingly, this book focuses heavily on beam physics, particularly on the optical components that are common across most accelerators.

Beam physics is the core of accelerator physics, involving both theoretical calculations and the practical challenges associated with implementing beam optics designs to transport particles effectively to their intended target. The book covers the design of essential beam optical components – both passive and active. Topics include the design and function of dipole magnets, quadrupole magnets, steerers, scanners, electrostatic dipoles and quadrupoles, sextupoles, radio frequency cavities, bunchers, choppers, electrostatic accelerating tubes, and more.

The transfer matrix approach is used extensively to calculate design parameters for beam optical components, followed by discussions of the hardware design and practical difficulties encountered. To further illustrate the concepts, the open-source beam optics code COSY Infinity is employed to demonstrate first-order beam optics through various optical components. The designs are explained in a general manner so that readers can adapt them to their specific requirements. To access the COSY Infinity code, registration is required on the website of the corresponding research group at the Center for Dynamical Systems, Michigan State University, as detailed below:

<https://www.bmdynamics.org/cosy/register.htm>

Registration instructions are available at:

<https://www.bmtdynamics.org/cosy/>

For any queries related to COSY Infinity, please contact:

support@cosyinfinity.org

I would like to express my sincere gratitude to Dr. Martin Berz and Dr. Kyoko Makino, Department of Physics, Michigan State University, for granting permission to use the COSY Infinity code to generate the beam optics diagrams used throughout this book.

As you read through the pages of *Charged Particle Beam Physics: An Introduction for Physicists and Engineers*, my hope is that you will find the knowledge and insights that will help you to achieve a particular goal or understanding as primary source of information on the exact topic of accelerator physics. This book is meant to be a resource, a guide, and a companion in your journey through world of particle accelerators.

Thank you for taking the time to engage with this work. I am excited to share it with you and look forward to the conversations and ideas that it may inspire. I dedicate this book to the application of particle accelerator technology for the betterment of human life and the peaceful advancement of mankind.

New Delhi, India
August 31, 2024

Sarvesh Kumar

