Chapter 1

Introduction

The act of colliding subatomic particles at very high energy is not merely a destructive act; it is, more profoundly, a creative one.

- *Matt Strassler*

1.1 Background to the study

Particles are the fundamental building blocks of matter that forms the core of everything in the universe. Studying particles and their interactions is a crucial component for comprehending the behaviour and properties of matter, from the smallest atoms to vast cosmic structures.

The theoretical understanding of particle accelerators can be traced back to the earliest discoveries of electrostatics, most notably that of pre-Socratic Greek philosopher, astronomer and mathematician Thales of Miletus, who is often credited with the earliest recorded observation of electrostatic forces [1]. These early insights laid the groundwork for more advanced studies of electromagnetic phenomena, that would ultimately lead to the experimental studies and development of the first particle accelerators in the 20th century.

Particle accelerators are devices that use electromagnetic fields to propel charged particles to high speeds and collide them together or with specific targets. These collisions can result in a release of energy, nuclear reactions, and particle creation and decay [2]. The insights gained from these collisions not only advance our understanding of fundamental and quantum physics, but also drive innovation across a range of industries by enabling the development of new technologies and techniques with wide-reaching applications.

While large particle accelerators such as the Large Hadron Collider aim to collide subatomic particles at near-light speeds, this study focuses on a more accessible, scaled-down demonstrator. The Tiny Big Magnetic Particle Accelerator (TBMPA) aims to explore the fundamental principles of acceleration, control, sensing, and timing in a simplified and safe environment. The system accelerates ball bearings around a closed track using magnetic fields, providing insights into the control and synchronization challenges faced by larger-scale accelerators.

In particle physics experiments, while significant investigations are conducted, there is often limited control over the particles used in these studies. If finer control and sensing could be achieved - potentially through advanced modeling techniques like those offered by TBMPA - this could enable more simultaneous experiments on a smaller research scale to explore particle properties, isotope formation, and related phenomena more effectively.

1.2 Objectives of this study

This section defines the objectives and deliverables of this research: detailing the specific problems to be investigated and the underlying purpose of the study.

1.2.1 Problems to be investigated

This research aims to address several key questions related to the control, timing and sensing of particle accelerators on a smaller scale. The primary problems to be investigated include:

1. The design considerations that are necessary for ensuring the safe and accurate operation of the accelerator.
2. How magnets can be used effectively to move and adjust the speed of objects within an enclosed track.
3. The optimal timing for activating the magnets to control the speed of the moving object.
4. The accurate detection and characterisation of the moving object using sensors.

1.2.2 Purpose of the study

The purpose of this research is to gain some insight into the challenges of particle accelerators, specifically aspects of their control and their timing and sensing synchronisation. By investigating these principles in a simplified model, this research aims to offer potential insights into more complex and larger scale particle accelerators. The results will be significant not only for academic purposes, but also for future innovations in particle physics where fine control over particle movement is critical. The findings could also have broader applications in industrial systems where precision control of moving objects is necessary.

1.3 Scope and Limitations

The scope of this research focuses on the design, operation, and control and detection systems of a small-scale particle accelerator model. The deliverables of this research is outlined below:

1. Well documented requirements and user guidelines.
2. Functional analysis of the system, including the anticipated performance.
3. Design trade-off analysis.
4. Design, construction, integration, and testing of the system.
5. Report integrating the above steps.

The limitations of this research include budget, time, and limited available information on the modelling of low-speed particle acceleration models and control mechanisms. There is a budget of R1500 for the components for the construction of the TBMPA, as well as component availability limiting the type and number of sensors and magnets that can be implemented. There is also a strict time restraint of 12 weeks allocated to the research project.

1.4 Plan of development

This report is organised into several key sections, each of which are briefly outlined below.

Chapter 2 presents a comprehensive literature review of the underlying theory, as well as discusses existing particle accelerators and demonstrator models and their applications.

Chapter 3 outlines the requirements analysis and methodology employed in the design and construction of the TBMPA model.

Chapters 4 presents the results, detailing the performance of the system, and the data and measurements collected.

Chapters 5 discusses the relevance of the results and how they fit into the theoretical work found in existing literature.

Chapter 6 presents the conclusions for this research project and discusses the extent to which the objectives were satisfied.

Chapter 7 provides recommendations for further work and potential future applications.