CHAPTER I
INTRODUCTION

1.1 Introduction

Accelerator Mass Spectrometry (AMS) is a powerful and precise technique widely used for radiocarbon dating, allowing researchers to determine the age of carbon-based materials by measuring the ratio of ^{14}C to stable isotopes such as ^{12}C and ^{13}C in a sample (Harris, 1987). AMS offers significant advantages over traditional radiometric methods, including gas proportional counting and liquid scintillation counting. It requires much smaller sample sizes and delivers higher precision, making it invaluable for dating samples that are tens of thousands of years old. This capability has greatly benefited fields such as archaeology, geology, and environmental science. Additionally, AMS offers rapid processing times and higher sensitivity, enabling researchers to construct more detailed chronological studies.

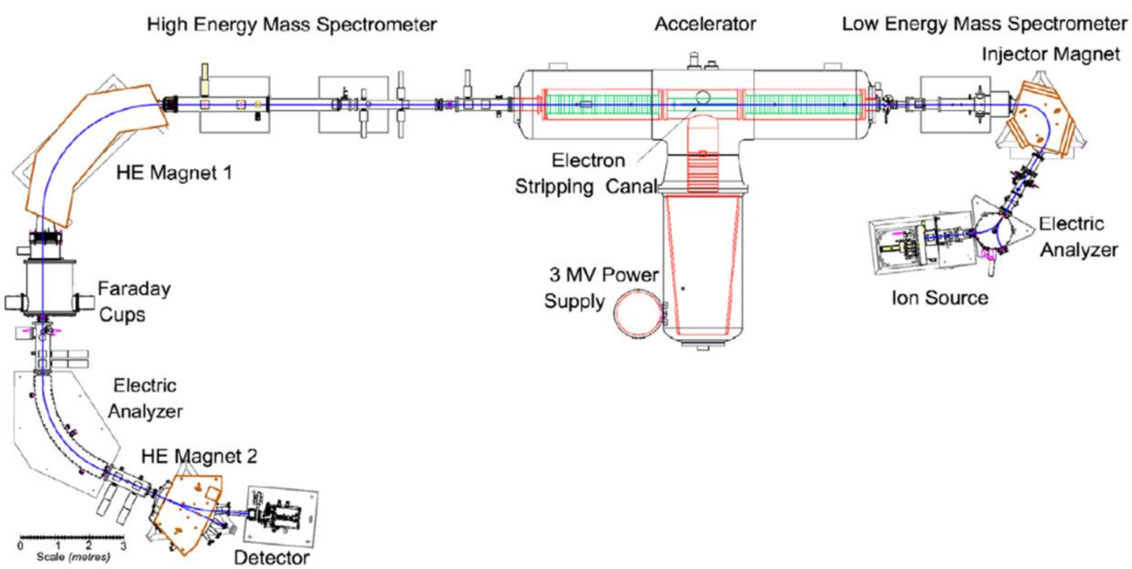

Figure 1.1 The AMS system at the Lalonde AMS Lab, University of Ottawa, operates with a terminal voltage of 3 MV (Kieser, W. E., 2023).

The development of AMS has undergone significant advancements to improve its efficiency and reduce the size of its systems. Historically, AMS systems were large as shown in Figure 1.1 and required high-energy accelerators to achieve the necessary sensitivity for isotope analysis. However, recent innovations have led to the creation of smaller AMS systems that operate at lower terminal voltages (200-300 kV), which significantly reduce both space and power requirements while maintaining high precision. These compact systems can use permanent magnets instead of electro-magnets, further cutting down on energy consumption and the need for cooling. Downsizing these systems not only reduces installation and operational costs but also integrates sample preparation units, enhancing the throughput and versatility of AMS for applications in environmental and archaeological research, among others (Keiser, W. E., 2023).

A critical component within AMS is the ion generation or negative carbon ion beamline, which ensures the stability and quality of the ion beam before it enters the main acceleration phase. The beamline process starts with the generation of negative carbon ions from ion source, after which the ions are extracted and formed into a beam. To maintain the beam's focus and alignment, electrostatic lenses and electrostatic deflectors are used. These elements help correct any initial misalignment and aberrations of ion beam, ensuring that the ion beam remains well-focused and follows the correct trajectory. This focus is essential for the beam to pass efficiently through the acceleration stages and to ensure accurate isotope separation in later steps.

The power supply and vacuum system are essential components for achieving the optimal performance of an AMS system. The power supply is responsible for generating the high-voltage electric potential required to accelerate ions in the beamline. This high voltage creates the electric fields that control the direction of the ions and increase their energy, ensuring that the ion beam remains stable and focused as it moves through the system. Simultaneously, the vacuum system maintains an ultra-high vacuum environment, typically in the range of 10^{-6} to 10^{-9} Torr, as described in the study (Liu et al., 2019). The vacuum system operates with a dynamic pressure of up to 6×10^{-7} Torr throughout the ion source and beamline, maintaining a stable environment crucial for reliable ^{14}C dating, particularly for archaeological and environmental samples. This vacuum is crucial for minimizing collisions between the ions and residual gas molecules, which could otherwise cause scattering and energy loss, degrading the quality of the beam. Together, the power supply and vacuum system ensure the stability, precision, and efficiency of the ion beam, ultimately contributing to the accuracy of isotope measurements in AMS.

The computer programs used for simulation and design are CST Studio Suite and SolidWorks for creating 3D models of the support structures inside the vacuum chamber, as well as various vacuum components. By conducting design and simulation in parallel, the simulation results become more realistic and reliable.

This work focuses on the design and simulation of a compact, low-energy negative carbon ion beamline for AMS. By designing and building the system in-house, the cost of purchasing a fully assembled unit can be reduced, and personnel capable of troubleshooting and minimizing future maintenance expenses can be developed. Furthermore, this will be Thailand's first radiocarbon dating instrument for archaeological artifacts, offering more affordable in-country testing services compared to sending samples abroad. This thesis presents the engineering design alongside results from computer simulations used to study how mechanical supports affect the electrostatic field and to determine the precise placement of all components inside and outside the vacuum chamber along the beamline. In addition, hands-on testing of the heated filament for carbon ion production was performed, the vacuum system was leak-checked to ensure operational readiness, and high-voltage power supplies were integrated beneath the table to help achieve a truly compact layout.

1.2 Research objectives

A compact system is designed to deliver a negative carbon ion beam with an energy of up to 40 keV, featuring adjustable beam focal length and steering in both X and Y directions. The system must maintain beam emittance below 10 π·mm·mrad·√MeV with a current of 50 μA at the aperture slit. Assembly tolerances, including allowable tilt angles and positional offsets, are to be defined based on alignment tools and design constraints. Electric fields within the ion source, octupole deflector, and Einzel lens are to be generated using specified parameters, including the integration of a heater, to determine power supply specifications. The beamline vacuum system is to be assembled using existing components available at SLRI, with optical components designed for compatibility. Additionally, a heater for the ionizer is to be developed, and a suitable construction method is to be identified to enable heating up to 1200°C.

1.3 Scope of thesis

1.3.1 This thesis focuses on the carbon ion beamline system, which is part of an accelerator mass spectrometer for radiocarbon dating. This beamline consists of four main components: the ion source, an octupole deflector, an Einzel lens, and an aperture slit.

1.3.2 Mechanical design of the ion source, octupole deflector and Einzel lens chamber using SolidWorks.

1.3.3 CST Studio Suite is used to study the electric field and perform particle simulations, measure beam properties (such as beam emittance, beam position, beam size, and focal length), and investigate the effects of structural supports on the electric field.

1.3.4 Primarily, existing vacuum components and chambers, along with a scroll pump and a turbomolecular pump from SLRI, are utilized to minimize costs.

1.4 Outline of thesis

This thesis is divided into five chapters. Chapter I is the Introduction, consisting of the background, objectives, and scope of the work. In Chapter II, an overview of AMS is provided, followed by a discussion on the development of AMS and ongoing efforts to downsize AMS systems. The role of electrostatic components in the ion beamline, including the octupole deflector and Einzel lens, is explained, and Maxwell's equations for particle-tracking simulations in CST Studio Suite are described. Chapter III is divided into three parts: the first presents CST simulations; the second describes the assembly of the compact system, including vacuum components, vacuum leak checking, and high-voltage power supplies; and the third details the development of the heater for the ionizer and filament heating inside the vacuum chamber. In Chapter IV, the experimental results are presented and discussed. Finally, Chapter V provides a summary of the findings along with concluding remarks.