

CONTENTS

	Page
ABSTRACT IN THAI.....	I
ABSTRACT IN ENGLISH.....	III
ACKNOWLEDGEMENTS.....	V
CONTENTS.....	VI
LIST OF TABLES.....	IX
LIST OF FIGURES.....	X
CHAPTER	
I INTRODUCTION.....	1
1.1 Introduction.....	1
1.2 Research objectives.....	3
1.3 Scope of thesis.....	4
1.4 Outline of thesis.....	4
II LITERATURE REVIEWS	5
2.1 Accelerator Mass Spectrometry (AMS).....	5
2.2 Development of AMS.....	6
2.3 Mini Carbon Dating System (MICADAS)	8
2.4 Electrostatic deflector.....	10
2.5 Electrostatic lens.....	13
2.6 Heater for ionizer	16
2.6.1 Design of the ionizer from HeatWave Labs, Inc.	17
2.6.2 Properties of MoRe alloy.....	18
2.7 Particle tracking solver in CST Studio Suite	21
2.7.1 Finite element analysis.....	21
2.7.2 Equation of motion (Lorentz force law).....	22
2.7.3 Maxwell's equations.....	22
2.7.3.1 Gauss's law (Electric).....	23
2.7.3.2 Gauss's law for magnetism.....	23
2.7.3.3 Faraday's law.....	23
2.7.3.4 Ampère - Maxwell law.....	23

CONTENTS (Continued)

	Page
III RESEARCH METHODOLOGY.....	24
3.1 Simulation using CST Studio Suite.....	24
3.1.1 Particle tracking simulation.....	24
3.1.1.1 Mesh refinement.....	25
3.1.1.2 Convergence study.....	26
3.1.1.3 Transfer source via define particle export interface.....	27
3.1.2 Ion source simulation.....	29
3.1.3 The study of miss alignment of the octupole deflector.....	31
3.1.4 Einzel lens simulation.....	33
3.1.4.1 The study of effects from mounting support.....	33
3.1.4.2 The study of focal range.....	35
3.1.4.3 The study of miss alignment.....	36
3.1.5 Low-energy negative carbon ion beamline simulation.....	37
3.2 Low-energy beamline design.....	39
3.2.1 Vacuum system.....	39
3.2.1.1 Existing vacuum components at SLRI.....	39
3.2.1.2 Leak checking by helium detector.....	43
3.2.2 High Voltage Power Supply (HVPS).....	45
3.2.2.1 HVPS for ion source.....	45
3.2.2.2 HVPS for octupole deflector.....	46
3.2.2.3 HVPS for Einzel lens.....	46
3.2.2.4 High voltage isolation transformer.....	46
3.2.3 Integrated system.....	47
3.3 The development of heater for ionizer.....	47
3.3.1 Calculation and design of the toroidal heater.....	47
3.3.2 Fabrication of the toroidal heater.....	49
3.3.3 Experimental setup.....	51
IV RESULTS AND DISCUSSION.....	52
4.1 Computer simulation results.....	52
4.1.1 Convergence study.....	53
4.1.2 The study of miss alignment of the octupole deflector.....	54
4.1.3 Einzel lens simulation results.....	56
4.1.3.1 The study of effects from mounting support.....	56

CONTENTS (Continued)

	Page
4.1.3.2 The study of focal range.....	59
4.1.3.3 The study of miss alignment.....	61
4.1.4 Low-energy negative carbon ion beamline simulation results....	62
4.2 Low-energy beamline design	64
4.2.1 Leak checking by helium detector	64
4.2.2 High voltage power supply	64
4.2.3 Integrated system.....	66
4.3 The development of heater for ionizer.....	67
V CONCLUSION.....	72
REFERENCES.....	73
CURRICULUM VITAE.....	78

LIST OF TABLES

Table		Page
2.1	Power Consumption of the Ionizer Heater at Different.....	18
2.2	Mechanical, Physical, Electrical, and Thermal Properties of MoRe Alloy	19
4.1	Acceptable tolerances for the central electrode of the Einzel Lens.....	62
4.2	Recording data on MoRe filament heating under vacuum conditions.....	68

LIST OF FIGURES

Figure	Page
1.1 The AMS system at the Lalonde AMS Lab, University of Ottawa, operates with a terminal voltage of 3 MV.....	1
2.1 The layout of AMS system at Japan Atomic Energy Agency Accelerator Mass Spectrometry facility at Tono (JAEA-AMS-TONO)	6
2.2 The layout of MICADAS. With its small dimensions of $2.5 \times 3 \text{ m}^2$	7
2.3 Simplified diagram of the ion optics of the MICADAS system.....	8
2.4 Octupole deflector.....	10
2.5 The schematic design of the octupole deflector.....	11
2.6 The horizontal (a) and vertical (b) profiles of a 40 keV C^- beam horizontally deflected with ΔV_y set to zero, while ΔV_x is varied from 0 to +300 V.....	11
2.7 The simulated deviated angle of a 40 keV C^- beam after passing through the deflector as a function of ΔV	12
2.8 The emittance of the 40-keV C^- beam entering the deflector at 40 mm from source.....	12
2.9 Cutaway view of ion trajectories in an Einzel lens.....	13
2.10 Geometry of the ion source, electrostatic Einzel lens, and analyzing magnet implemented via the SIMION code	14
2.11 Simulation results for beam transmission in two different modes of the Einzel lens: (a) accel-decel mode and (b) decel-accel mode	14
2.12 The ion beam envelope and electric field component on the beam axis beam when the electrostatic einzel lens was biased with (a) 46,903 V and (b) -20,951 V	15
2.13 The emittance of the ion beam when the ES Einzel lens was biased with (a) 46,903 V and (b) -20,951 V	15
2.14 Cross-sectional drawing of an electro-static einzel lens with three cylindrical tube electrodes	16
2.15 Drawing of the Ø1.38-inch ionizer heater from HeatWave Labs.....	17
2.16 Electrical Resistivity of TZM Alloy, HT Alloy, and Pure Molybdenum vs. Temperature	20

LIST OF FIGURES (Continued)

Figure	Page
2.17 Mesh types for computer simulation. (a) Tetrahedral mesh (b) Hexahedral mesh	21
3.1 Flow chart of particle tracking simulation in CST Studio Suite.....	25
3.2 Mesh Generation for the particle tracking solver module in CST.....	26
3.3 The global mesh settings, where the N_mesh variable is defined in the mesh properties, are used with the parameter-sweep function to perform the convergence study.....	26
3.4 In the parameter sweep function, the N_mesh variable is swept from 20 to 200 in steps of 20, yielding 10 values (20, 40, 60, ..., 200) and progressively increasing the mesh density.....	27
3.5 Defining the particle export interface. a) Boundary and position setup for particle export at the ion focus point, located 160 mm from the emission point; the boundary plane is sized larger than the beam envelope. b) Example of the particle export interface (blue plane) defined for the ion source, using the known focal position of the ion beam.....	28
3.6 Setting the kinetic energy and angular spread of the particle sources to model the effects of HVPS ripple and the sputtering process respectively.....	29
3.7 Simulation results of the ion source a) Trajectories of ^{12}C , ^{13}C , and ^{14}C ions focused at 160 mm from the source. b) Particle distribution image at the focal point c) Energy spreads at the focal point.....	30
3.8 Comparison of a new ionizer (left) and a used ionizer (right), showing burn marks at the center caused by sputtered ions spreading in all directions and striking the surface.....	31
3.9 The octupole deflector model has rods each 10 mm in diameter and a total inner diameter of 40 mm	32
3.10 The aperture slit design consists of four independently adjustable blades, each movable along the $\pm x$ and $\pm y$ axes, allowing a maximum square opening of $20 \times 20 \text{ mm}^2$ or complete closure. Each blade also serves as a current collector to measure and monitor the ion beam. a) Upstream side b) Downstream side.....	33
3.11 The ratio of the Einzel lens lengths (ring1 : gap : ring2).....	34

LIST OF FIGURES (Continued)

Figure	Page
3.12 The Einzel lens model 1 (43 : 21 : 64 mm).....	34
3.13 The Einzel lens model 2 (40 : 6 : 82 mm).....	34
3.14 Optimizer Function Settings in CST Studio Suite a) Definition of variables and their ranges for the solver to vary. b) Specification of the optimization goals.....	35
3.15 The cross section of einzel lens design includes mounting supports (shown on the leftmost side) shared with the octupole deflector	36
3.16 The cross-section of the low-energy negative carbon ion beamline shows the details and positions of the main components: the ion source (orange), the octupole deflector (pink), the Einzel lens (green), and the aperture slit (blue). The insulator segment is also highlighted. a) Beamline with external details. b) Simplified beamline model for particle-tracking simulation in CST.....	37
3.17 Analysis of the ion beam using particle monitors. a) The 101 monitors spanning from the ion source focal point through and slightly beyond the aperture slit, including Monitor 1 at the slit and Monitor 2 along the beam path. b) Template based post processing showing the results as the ion beam passes each monitor.....	38
3.18 6-Ways Cross Chamber, 8" OD, Sphere Body 9 inch	39
3.19 Adapter CF203 to CF152.....	40
3.20 6-Ways Cross Chamber, 6" OD size 270 mm.....	40
3.21 6-Ways Cross Chamber, 6" OD size 220 mm.....	41
3.22 Edge weld bellow and alignment studs.....	41
3.23 Vacuum gate valve.....	42
3.24 Glass view port.....	42
3.25 Setup of the leak-testing system using a Pfeiffer Adixen ASM 340 leak detector at SLRI.....	43
3.26 Monitoring and recording the leak rate and inlet pressure according to the operating instructions.....	44
3.27 Simplified diagram of the power-supply zones for generating electric fields in the cesium sputter source for AMS at SLRI.....	45

LIST OF FIGURES (Continued)

Figure	Page
3.28 Toroidal heater with 40 turns installed inside the ionizer body.....	48
3.29 Fabrication of the toroidal heater coil by SLRI's machine shop	50
3.30 3D-printed prototype of the tamper by SUT QLAB	50
3.31 Experimental setup for heating the MoRe coil in the vacuum system.....	51
4.1 Optical layout of the negative carbon ion beamline.....	52
4.2 Optimal mesh size of the ion source model	52
4.3 Convergence study graphs used to select the optimal mesh size for the ion source model. a) $rms(position_x)$ vs. plane position b) Emittance vs. plane position	53
4.4 Convergence of gun iteration vs. charge accuracy.....	54
4.5 Comparison of particle images at the aperture slit between perfect alignment (black) and tilt = 2° with offset = 2 mm (red). The black square indicates the maximum slit opening of $20 \times 20 \text{ mm}^2$	55
4.6 Comparison of normalized ion density at the aperture slit for perfect alignment (black) and for the worst-case misalignment with $\theta = 2^\circ$ and offset = 2 mm (red), shown as a histogram.....	56
4.7 Simulated beam image at the focal plane using a -20 kV bias on the central electrode. a) Model 1 with ratio of 43: 21: 64 mm. b) Model 2 ratio of 40: 6: 82 mm. The insulator segment is shown in blue.....	57
4.8 The electric field inside Einzel lens model 1 is shown in a cross-sectional view to illustrate the electric field perturbations around the support rods (black arrows)	58
4.9 Comparison of the focal distances of Einzel lens Model 1 and Model 2.....	59
4.10 Cross-sectional view of the electric field within the Einzel lens, showing how the field strength varies with the applied bias voltage.....	59
4.11 Graph showing the relationship between plane position and $rms(position_x)$ for various V_Einzel values. The plot also indicates the distance from the source to the center of the Einzel lens (389 mm) and the distance from the lens center to the aperture slit (476 mm).....	60
4.12 Trajectories of negative carbon ions through the Einzel lens. a) -17.5 kV, producing an almost parallel beam. b) -20,139 V (from the optimizer), focused exactly at the aperture slit. c) -30 kV, the maximum output of the power supply.....	61

LIST OF FIGURES (Continued)

Figure	Page
4.13 Trajectories of C^- ions through the Einzel lens with a middle electrode 1.6° tilt and 1.6 mm offset from the optical axis.....	61
4.14 Trajectories of C^- ions passing through the perfectly aligned low-energy negative carbon ion beamline.....	62
4.15 Particle images at the aperture slit for the perfectly aligned low energy negative carbon ion beamline. The black square indicates the maximum slit opening of 20 × 20 mm ² . Figure a) mark size = 1.5 and Figure b) mark size = 0.1.....	63
4.16 Energy spread with FWHM at the aperture slit location.	63
4.17 Digital display of the helium leak rate during vacuum component testing	64
4.18 Diagram of the HVPS configuration used in the negative carbon ion beamline.....	65
4.19 A compact system design for the low-energy negative carbon ion beamline, comprising a tabletop vacuum system integrated with HVPS units beneath the table. The ceramic insulator standoffs are shown in red, and the isolation transformer is shown in black.....	66
4.20 Pressing the tamper into modeling clay in the ionizer body's grooves, simulating the application of alumina paste (Al_2O_3)	67
4.21 MoRe heater coil a) Before installation b) During testing at 800 °C	69
4.22 The graph shows the relationship between temperature and resistance....	69
4.23 The graph shows the relationship between temperature and power consumption.....	70
4.24 The graph shows the relationship between temperature and pressure in vacuum system.....	71