DESIGN AND DEVELOPMENT OF SHAPE MEMORY ALLOY BASED NOVEL ACTUATORS FOR MINIMALLY INVASIVE SURGERIES

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Degree of Master of Philosophy

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January 2022

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy in Mechanical Engineering

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DECLARATION

I declare that this is my work, and this dissertation does not incorporate without acknowledgment of any material previously submitted for a Degree or Diploma in any other Universities or institutes of higher learning and to the best of my knowledge and believe it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

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Signature of the Supervisor(s): Date:

Prof. Y.W.R. Amarasinghe

Dr. N.W.N. Dayananda

ABSTRACT

This work relates to the design and development of Shape Memory Alloy (SMA) based novel actuators for Minimally Invasive Surgeries (MIS). Compared to conventional open surgery, MIS procedures are favorable and developments are possible towards improving the effectiveness of MIS. Handheld slender instruments used in MIS are with limited degrees of freedom achieved using conventional actuation mechanisms which possess disadvantages in handling, durability, and cost.

In this study, an SMA-based approach was considered to improve the operation of an MIS tool effectively. The complex behaviour of SMA led to the investigation of material behaviour before the application-oriented study. SMAs are smart alloys that are capable of remembering a parent shape according to the heat treatment (HT) temperature and aging time providing unique activation temperatures. Commercially available binary SMA material that is known as NiTiNOL was used for the study. NiTiNOL was subjected to different HT conditions and Differential Scanning Calorimetric (DSC) analysis was performed on the resulting material to obtain transformation temperatures. Test results demonstrated the ability to alter activation temperature by varying the HT conditions. Also, the samples were observed under an Optical Microscope (OM) and Scanning Electron Microscope (SEM) to identify morphology and elemental composition by Energy Dispersive X-Ray Spectroscopy (EDX) respectively. Furthermore, an SMA spring actuator element was fabricated using a NiTiNOL wire through a novel fixture to obtain desired spring parameters and geometry. NiTiNOL wire was held in the fixture undergoing a HT at experimented temperatures and aging times. Then, spring actuators were characterized based on maximum attainable force using a specially developed apparatus. A customizable hardware controller and a software interface were developed to set values, monitor temperature, and force output. Using the mentioned apparatus, the controller was validated in both temperature and force feedback controlling modes based on a Proportional-Integral-Derivative (PID) type controller.

Two linear actuators were designed and developed using the characterized spring element. Firstly, an actuator was developed based on external heating using a heated fluid and cooled fluid to heat and cool the spring element, respectively. A novel actuator structure was developed to facilitate the spring element with leak-proof assembly and was used as the drive source of a gripper mechanism. Strain gauge-based force sensing and PID-based force feedback controlling methods were introduced to the gripper assembly. The second approach was utilizing a Joule heating-based method for activation which the passing current generates heat due to the inherent resistance of NiTiNOL resulting in an increment in temperature. The

actuator was characterized in terms of stroke and then introduced to a laparoscopic retractor application to control the flexion-extension motion. A specially developed apparatus and a software interface are used to control parameters and acquire data. Finally, the retractor tool was characterized in terms of stroke.

Key Words: Shape Memory Alloy; Minimally Invasive Surgeries; Differential Scanning Calorimetry; PID Controlling; SMA Spring Actuated Gripper; Laparoscopic Retractor; External Heating; Joule Heating

DEDICATION

I dedicate this dissertation work to my family and my teachers. A special feeling of gratitude to my loving parents, Mr. Rathnasena and Mrs. Malani Weerasooriya and my loving wife Mrs. Thilini de Silva, and my lovely daughter Miheli Aryana, whose words of encouragement and push for tenacity ring in my ears. Finally, I'm grateful for my fellow Sri Lankan citizens who are paying taxes to sustain free education unconditionally.

ACKNOWLEDGMENT

I am deeply grateful to the Head of the Department, Department of Mechanical Engineering Dr. Himan Punchihewa, and all the academic and non-academic staff of the department for their constant encouragement in the period of research. Especially my research supervisors, Prof. Y.W.R. Amarasighe, Dr. N.W.N. Dayananda who gave me support and attention towards my work. Without their keen supervision, none of this would have been possible for me alone. I consider myself very fortunate for being able to work with such resourceful individuals.

Moreover, I'm particularly grateful to the research coordinator of the Department of Mechanical Engineering Dr. Nalaka Samaraweera, and the members of the progress review panel Prof. Ruwan Gopura and Dr. Angelo Karunarathne for their valuable comments and advice given throughout the research to guide me on the correct path.

Furthermore, I would like to express my heartfelt gratitude to Mr. Janaka Basnayake who gave me the technical expertise on electronic developments and the support and encouragement he gave me throughout the research is invaluable. Also, I would like to extend my gratitude to Mr. Peshan Sampath, Mr. Dimuthu Wijethunge, Mr. Praveen Nuwantha Gunarathne, Mr. Eranga De Silva, and Dr. Dumith Jayathilake for their assistance given me throughout the research.

Also, I would like to thank, Mr. Suranja Lakmal from the Open Univesity of Sri Lanka (OUSL), Mr. Sandaruwan Jayalath, Mrs. Thilini Thathsara from the Institute of Technology University of Moratuwa (ITUoM), and Mrs. Rashmi Kumarasinghe from the Sri Lanka Institute of Nanotechnology (SLINTEC) for their valuable support given me by facilitating and spending time with the testing carried out throughout the research at their facilities.

Last but not the least, I owe my thankfulness to Mr. R.A.D.N.S. Ranasinghe, Mr. K.D.C. Jeewantha, and Mr. M.N.M. Musammil from the Mechatronics and MEMS/NEMS laboratory for providing me the facilities required for conducting my research works whenever required. Also, I'm grateful for the help received by Mrs. T.L.K. Kumari from the Applied Mechanics Laboratory for providing equipment for testing and Mr. M.D.S. Ananda from the Machine shop for performing precision fabrication processes on several components required for the testings conducted.

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LIST OF ABBREVIATIONS

Abbreviation	Description
ADC	Analogue to Digital Converter
ALM	Applied Loading Method
CAD	Computer Aided Design
CCD	Charged Couple Discharge
DAQ	Data Acquisition
DOF	Degree of Freedom
DSC	Differential Scanning Calorimetry
EDX	Energy-Dispersive X-ray
ERM	Electrical Resistance Method
FEA	Finite Element Analysis
FET	Field Effect Transistor
GUI	Graphical User Interface
HTSMA	High Temperature Shape Memory Alloys
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
LED	Light Emitting Diode
LIFA	LabVIEW Interface For Arduino
MBD	Multi Body Dynamics
MEMS	Micro Electromechanical Systems
MIS	Minimally Invasive Surgeries
MSMA	Magnetic Shape Memory Alloys
NiTiNOL	Nickel Titanium Naval Ordnance Laboratory

OM	Optical Microscopy
OWSME	One Way Shape Memory Effect
PD	Proportional Derivative
PE	Pseudo Elasticity
PID	Proportional Integral Derivative
PMMA	Poly Methyl Methacrylate
PWM	Pulse Width Modulation
SEM	Scanning Electron Microscope
SMA	Shape Memory Alloy
SME	Shape Memory Effect
SMM	Shape Memory Material
SMP	Shape Memory Polymers
SPS	Samples Per Second
TWSME	Two Way Shape Memory Effect
USB	Universal Serial Bus
VAR	Vacuum consumable Arc
VB	Visual Basic
VGC	Variable Geometry Chevron
VIM	Vacuum Induction Melting
VISA	Virtual Instrument Software Architecture

LIST OF APPENDICES