

**MULTILAYERS PREISACH MODEL FOR
MAGNETORHEOLOGICAL ELASTOMER
(MRE) MODELLING OPTIMIZED WITH
PARTICLE SWARM OPTIMIZATION (PSO) AND
PID-SKYHOOK CONTROL OF AN ACTIVE
FRONT BUMPER SYSTEM**

‘ALAWIYAH HASANAH BINTI MOHD ALAWI

**MASTER OF SCIENCE
(MECHANICAL ENGINEERING)**

**UNIVERSITI PERTAHANAN NASIONAL
MALAYSIA**

2024

**MULTILAYERS PREISACH MODEL FOR MAGNETORHEOLOGICAL
ELASTOMER (MRE) MODELLING OPTIMIZED WITH PARTICLE
SWARM OPTIMIZATION (PSO) AND PID-SKYHOOK CONTROL OF AN
ACTIVE FRONT BUMPER SYSTEM**

‘ALAWIYAH HASANAH BINTI MOHD ALAWI

Thesis submitted to the Centre for Graduate Studies, Universiti Pertahanan Nasional
Malaysia, in fulfilment of the requirements for the Degree of Master of Science
(Mechanical Engineering)

ABSTRACT

In this study, an active front bumper device is designed to reduce the impact on a vehicle in the case of a road accident. Road accidents can inflict harm on an automobile's body, especially on the front bumper, which is referred to as a crumple zone and can injure passengers. In order to reduce the effect of a frontal collision, an active front bumper system based on the Magnetorheological elastomer (MRE) isolator was developed. This is a result of MRE's exceptional ability to absorb impact force in the presence of a magnetic field. Therefore, the goal of this work is to create a mathematical model of a real vehicle's crumple zone, analyze the dual-acting MRE isolator's impact behavior, and create a control strategy for assessing the MRE isolator's impact behavior in three different types of impact collisions which are light, medium, and hard. The initial stage of the methodology was the development of a mathematical model that represents the crumple zone. This model is developed using Multiple Kelvin Model (MKM) that consists of seven mass-spring-damper systems. The model is optimized for the parameters of spring stiffness, k and damping coefficient, c using Particle Swarm Optimization (PSO) methods. This optimization process is conducted in order to compare the simulation outcomes with the experimental results obtained from Actual Crash Data (ACD). Subsequently, a double acting Magnetorheological Elastomer isolator is fabricated and simulated using a Multi-Layer Preisach model to characterize the impact behavior of a double acting MRE isolator. Next, the model is validated using experimental data from drop impact tests on MRE samples with the various currents ranging from 0-2 A and trained using PSO. In addition, an interpolate model of the MRE isolator is used to predict the 0.3,

0.7, 1.3, and 1.7 A force and displacement characteristics for the intermediate current. Furthermore, the best performance of the control structure can be achieved by using a combination of controllers such as Proportional-Integral-Derivative (PID) and skyhook controller for the active front bumper model. The present study investigates the efficacy of the suggested control system in attaining the desired force during impact collisions across three distinct scenarios which are light impact (83.25 kN), medium impact (333.02 kN), and heavy impact (749.28 kN). The vehicle test rig is utilized to conduct experiments using varying masses of impactors in order to obtain measurements of acceleration and displacement. The implementation of the active front bumper system has demonstrated a significant reduction in the magnitude of frontal collisions. Specifically, the system has achieved a reduction of 50.71%, 47.32%, and 33.47% in acceleration results, and 50.00%, 26.96%, and 13.80% in displacement results. These outcomes have been seen across three distinct impact force cases, namely light, medium, and strong collisions.

ABSTRAK

Dalam kajian ini, sebuah sistem bumper hadapan aktif telah direka untuk mengurangkan impak pada bahagian hadapan kenderaan ketika terlibat dalam kemalangan jalan raya. Kemalangan jalan raya boleh menyebabkan kerosakkan terhadap badan kenderaan, terutamanya pada bumper hadapan yang dikenali sebagai zon renyuk yang boleh mengancam nyawa penumpang. Bagi mengurangkan kesan perlanggaran hadapan, sistem bumper hadapan aktif berasaskan isolator Magnetorheological elastomer (MRE) telah dibangunkan. Ini adalah hasil daripada keupayaan luar biasa MRE yang mampu menyerap daya impak dengan kehadiran medan magnet. Oleh itu, objektif kajian ini adalah untuk mencipta sebuah model matematik zon renyuk berdasarkan kenderaan sebenar bagi menganalisis tingkah laku impak isolator MRE dwi tindakan, dan merangka strategi kawalan yang berkesan untuk menilai tingkah laku impak isolator MRE dalam tiga tahap perlanggaran yang berbeza iaitu ringan, sederhana, dan kuat. Fasa awal metodologi adalah pembangunan model matematik yang mewakili zon renyuk kenderaan. Model ini direka menggunakan pendekatan Kelvin-Voigt tunggal yang ditingkatkan menjadi tujuh darjah kebebasan jisim-pegas-peredam. Parameter model ini yang terdiri daripada (k) dan (c) dioptimumkan menggunakan kaedah Particle Swarm Optimization (PSO). Proses pengoptimuman ini dijalankan untuk membandingkan hasil simulasi dengan hasil ujian perlanggaran sebenar yang diperoleh dari Actual Crash Data (ACD). Seterusnya, isolator Magnetorheological elastomer (MRE) dwi tindakan dibina dan disimulasikan menggunakan model Multi-Layer Presaich untuk meramalkan tingkah laku impak isolator MRE dwi tindakan. Kemudian, model ini disahkan dengan data

dari ujian impak jatuh ke atas sampel MRE dengan arus yang berlainan dari 0-2 A yang dilatih menggunakan PSO. Selain itu, model interpolasi isolator MRE digunakan untuk meramalkan ciri-ciri daya dan anjakan pada arus pertengahan iaitu 0.3, 0.7, 1.3, dan 1.7 A. Tambahan pula, prestasi terbaik sistem bumper hadapan aktif dapat dicapai dengan menggunakan gabungan pengawal yang terdiri daripada Proportional-Integral-Derivative (PID) dan skyhook. Kajian ini telah membuktikan keberkesanan sistem kawalan yang dicadangkan dalam mencapai daya yang diinginkan semasa pelanggaran impak di tiga senario yang berbeza iaitu impak ringan (83.25 kN), impak sederhana (333.02 kN), dan impak kuat (749.28 kN). Rig ujian pelanggaran digunakan untuk menjalankan eksperimen dengan menggunakan pelbagai jisim pengimpak bagi mendapatkan ukuran pecutan dan anjakan. Pelaksanaan sistem bumper hadapan aktif telah menunjukkan pengurangan yang ketara dalam magnitud pelanggaran hadapan. Secara khususnya, sistem ini telah mencapai pengurangan sebanyak 50.71%, 47.32%, dan 33.47% dalam keputusan pecutan. Manakala, dalam keputusan anjakan adalah 50.00%, 26.96%, dan 13.80%. Pemerhatian ini telah dijalankan di tiga daya pelanggaran yang berbeza, iaitu pelanggaran ringan, sederhana, dan kuat.

ACKNOWLEDGEMENTS

Alhamdulillah. First and foremost, I want to pay my gratitude to ALLAH for granting me good health , wisdom, guidance, strength, a loving family, inspiring educators and supportive friends. This study and thesis would not have been completed without His grace. Additionally, I cannot overlook the most exemplary individual in the world and the most revered personality for whom ALLAH brought the entire universe into existence, Prophet Muhammad (Peace Be Upon Him).

Completion of this thesis was possible with the support of several people. Firstly, I would like to express my gratitude to my supervisor, Associate Professor Dr. Khisbullah Hudha, for his dedicated guidance, unwavering support, valuable advice, motivation, extensive expertise, and patience throughout the entire journey. I would also like to thank my co-supervisor, Dr. Zulkiffli Abd. Kadir for providing invaluable advice for my research.

Besides that, this research would not have been possible without the financial assistance based on FRGS grant, the Ministry of Higher Education of Malaysia, as well as the Faculty of Engineering, National Defence University of Malaysia (UPNM) for providing the opportunity to pursue my passion.

I would like to express my appreciation to Dr. Noor Hafizah Amer and Associate Professor Dr. Ku Zarina Ku Ahmad for their guidance in all the time of research. In addition, I would like to thank the laboratory staff Mr. Azman, Mr. Rizal and Mr. Junaidi for providing research facilities such as machines for impact testing and resources to accomplish my research work.

Needless to say, I owe a lot to my beloved parents: Mr. Mohd Alawi bin Abdul Hamid and Mrs. Ruslina binti Abdul Rahim for their continuous support, spiritual guidance, and love throughout my personal and academic life where they provided me with the best and gave me the strength to chase my dreams.

And last but not least, thanks to my supportive comrades Ms. Amrina Rasyada binti Zubir and Ms. Amira Ilyanie binti Ruslan who were with me at every moment throughout my Master journey and I hope that we can successfully completed it till the end. With the completion of this Master journey, I do believe that it will be a new beginning of another life chapter to gain more knowledge and discover them.

APPROVAL

The Examination Committee has met on **26 February 2024** to conduct the final examination of **‘Alawiyah Hasanah Binti Mohd Alawi** on his degree thesis entitled **‘Multilayers Preisach Model for Magnetorheological Elastomer (MRE) Modelling Optimized with Particle Swarm Optimization (PSO) and PID–Skyhook Control of An Active Front Bumper System’**.

The committee recommends that the student be awarded the of Master of Science (Mechanical Engineering).

Members of the Examination Committee were as follows.

Mej. Prof. Madya Ir. Dr. Razali bin Abidin

Fakulti Kejuruteraan

Universiti Pertahanan Nasional Malaysia

(Chairman)

Prof. Madya Ir. Dr. Saidi Ali Firdaus bin Mohamed Ishak

Fakulti Kejuruteraan

Universiti Pertahanan Nasional Malaysia

(Internal Examiner)

Ts. Dr. Mohamad Heerwan bin Peeiee

Fakulti Kejuruteraan

Universiti Malayisa Pahang

(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Mechanical Engineering)**. The members of the Supervisory Committee were as follows.

Associate Professor Dr. Khisbullah Hudha

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Main Supervisor)

Dr. Zulkiffli bin Abdul Kadir

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Co-Supervisor)

Dr. Noor Hafizah binti Amer

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Co-Supervisor)

Associate Professor Dr. Ku Zarina binti Ku Ahmad

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name : 'Alawiyah Hasanah Binti Mohd Alawi
Date of birth : 05 August 1998
Title : Multilayers Preisach Model for Magnetorheological Elastomer (MRE) Modelling Optimized with Particle Swarm Optimization (PSO) and PID – Skyhook Control of An Active Front Bumper System
Academic session : 2023/2024

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

☐ **CONFIDENTIAL** (Contains confidential information under the official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organisation where research was done)*

☐ **OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

Signature

**Signature of Supervisor/Dean of CGS/
Chief Librarian

980805-02-5624

IC/Passport No.

[Click here to enter text.](#)

**Name of Supervisor/Dean of CGS/
Chief Librarian

Date:

Date:

*If the thesis is CONFIDENTIAL OR RESTRICTED, please attach the letter from the organisation with period and reasons for confidentiality and restriction.

** Witness

TABLE OF CONTENTS

	TITLE	PAGE
	ABSTRACT	ii
	ACKNOWLEDGEMENTS	vi
	APPROVAL	viii
	APPROVAL	ix
	DECLARATION OF THESIS	x
	LIST OF TABLES	xiv
	LIST OF FIGURES	xvi
	LIST OF ABBREVIATIONS	xix
	LIST OF SYMBOLS	xxi
CHAPTER 1	INTRODUCTION	1
	1.1 Background Study	1
	1.2 Problem Statement	2
	1.3 Research Objectives	4
	1.4 Scope of Study	4
	1.5 Methodology	5
	1.6 Contributions of Study	10
	1.7 Thesis Organization	11
CHAPTER 2	LITERATURE REVIEW	13
	2.1 Introduction	13
	2.2 Classification of Vehicle Crash Impact	13
	2.3 Approaches to Reduce Vehicle Crash	20
	2.3.1 Preventive Measures for Pre-Collisions	20
	2.3.2 Preventive Measures for Post-Collisions	24
	2.4 MRE Damper Design	29
	2.5 Modelling Approach for Active Front Bumper System	31
	2.5.1 Maxwell Model	31
	2.5.2 Kelvin-Voigt Model	32
	2.5.3 Dynamic Three Mass Model	33
	2.6 Control Strategies Active Front Bumper System	35
	2.6.1 PID Controller	35
	2.6.2 Skyhook Controller	36
	2.6.3 Combination of Controller	38
	2.7 Optimization Model with Particle Swarm Optimization (PSO)	39
	2.8 Research Gap	41
	2.9 Chapter Summary	43
CHAPTER 3	CRUMPLE ZONE MODELLING USING MULTIPLE KELVIN MODEL	45
	3.1 Introduction	45
	3.2 Multiple Kelvin Model	46

3.2.1	Equation of Motion of the Multiple Kelvin Model	47
3.2.2	Development of Multiple Kelvin Model in MATLAB Simulink	49
3.3	Model Optimization Using PSO	51
3.4	Optimization of Model Parameters Using PSO	53
3.4.1	Effect of Varying Number of Iterations (N_i)	53
3.4.2	Effect of Varying Number of Particles (N_p)	56
3.4.3	Effect of Varying Inertia Weights (i_w)	59
3.5	Model Optimization Results	62
3.5.1	Performance Comparison of The Proposed Model	66
3.6	Chapter Summary	68
CHAPTER 4	DESIGN, CHARACTERIZATION AND MODELLING OF MAGNETORHEOLOGICAL ELASTOMERS UNDER IMPACT LOADING	70
4.1	Introduction	70
4.2	Design and Fabrication of Double Acting MRE Damper	71
4.3	Experimental Setup for Double Acting MRE Damper	75
4.4	Mathematical Model for MRE Double Acting MRE Damper	78
4.5	Optimization of Double Acting MRE Damper Modelling with PSO	80
4.5.1	Effects of Varying PSO Parameters	83
4.6	Interpolation MRE Model for Prediction Current	86
4.7	Validation of Results	87
4.7.1	Optimized Model Parameters	88
4.7.2	Comparison between Simulated Model with Experimental Data	90
4.7.3	Validation of Interpolated Model	96
4.8	Chapter Summary	100
CHAPTER 5	DEVELOPMENT OF ACTIVE FRONT BUMPER CONTROLLER AND EXPERIMENTAL TEST RESULTS	101
5.1	Introduction	101
5.2	Control Design for Active Front Bumper System in Simulation	102
5.2.1	PID and Skyhook Controller	103
5.2.2	Current Generator using On-Off Current Generator	104
5.3	Simulation Parameters and Results	105
5.4	Fabrication of Collision Test Rig	107
5.4.1	Universal Pendulum Impact Tester	108

5.4.2 Sled Impactor	110
5.4.3 Scaled Vehicle	111
5.5 Dimension Analysis Between Model and Prototype using Froude Similarity	112
5.6 Experiment Setup of Small Scaled Active Front Bumper System	114
5.6.1 Sensor Instrumentation	116
5.6.2 Experimental Testing of the Proposed Active Front Bumper System	118
5.7 Experimental Result of Active Front Bumper System for Different Impact Collision Test	120
5.7.1 Light Impact Collision	121
5.7.2 Medium Impact Collision	123
5.7.3 Hard Impact Collision	126
5.8 Chapter Summary	129
CHAPTER 6 CONCLUSIONS	159
6.1 Overview	130
6.2 Conclusion	131
6.3 Recommendations for Future Research	133
REFERENCES	135
APPENDICES	145
BIODATA OF STUDENT	165
LIST OF PUBLICATIONS	166

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 3.1	The initial parameters for the mass, spring and damper	51
Table 3.2	The optimized parameters for different number of iterations	56
Table 3.3	The optimized data for different number of particles	59
Table 3.4	The optimized data for different inertia weights	62
Table 3.5	The optimal k and c values	63
Table 3.6	The maximum percentage error for each model	68
Table 4.1	Composition of the MRE sample (Sobri et al., 2021)	75
Table 4.2	Parameters of the drop impact test	76
Table 4.3	Initial simulation parameter for PSO optimization	82
Table 4.4	Optimized parameters for current 0 A	90
Table 4.5	The maximum percentage of error in all five cases	96
Table 4.6	Percentage error for the interpolated model	100
Table 5.1	Simulation parameters for control design	107
Table 5.2	Comparison of maximum peak value	108
Table 5.3	Weight of plate impactor based three stages of impact	111
Table 5.4	Parameters for real and scaled vehicle	114
Table 5.5	Maximum peak value during light impact collision	124
Table 5.6	Displacement value during light impact collision	124
Table 5.7	Maximum peak value during medium impact collision	126
Table 5.8	Displacement during medium impact collision	126

Table 5.9	Maximum peak value during hard impact collision	129
Table 5.10	Displacement value during hard impact collision	129

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1.1	Flowchart of research work	6
Figure 2.1	Road accident and fatalities cases in Malaysia (The Star, 2023)	15
Figure 2.2	Head - on collisions (Brian, 2023)	17
Figure 2.3	Rear - end collisions (Bieber, 2022)	18
Figure 2.4	Side vehicle collisions (Anidjar & Levine, 2022)	18
Figure 2.5	One vehicle collision (Mikulec & Semela, 2020)	19
Figure 2.6	Multiple vehicle collision (Kevin, 2022)	20
Figure 2.7	Adaptive cruise control (Ziebinski et al., 2017)	21
Figure 2.8	Car navigation system using GPS (Haas et al., 2019)	22
Figure 2.9	Braking situations with and without ABS (Bhasin, 2019)	23
Figure 2.10	Forward collision warning system (Chen et al., 2013)	24
Figure 2.11	Front bumper system (Muhammad et al., 2017)	25
Figure 2.12	MRE with induced magnetic flux densities (Kashima et al., 2012)	29
Figure 2.13	Multilayer of MRE isolator (Yang et al., 2014)	30
Figure 2.14	Maxwell model (Athalye et al., 2018)	32
Figure 2.15	Kelvin-Voigt model (Papi, 2022)	33
Figure 2.16	Dynamic three mass model (Lukoševičius et al., 2020)	34
Figure 2.17	PID controller for MR system (Borase et al., 2020)	36
Figure 2.18	Concept of skyhook controller (Choi et al., 2016)	38

Figure 3.1	Seven lumped masses of Multiple Kelvin model	46
Figure 3.2	Block diagram of the Multiple Kelvin model	50
Figure 3.3	The outcome of varying the number of iterations, N_i	55
Figure 3.4	The outcome of varying the number of particles, N_p	58
Figure 3.5	The outcome of varying inertia weights, i_w	61
Figure 3.6	The optimum model parameters	65
Figure 3.7	Comparison with others model	67
Figure 4.1	Double acting MRE damper	72
Figure 4.2	MRE fabrication process	74
Figure 4.3	Drop impact test machine	76
Figure 4.4	Force-displacement characteristics of MREs	77
Figure 4.5	Block diagram of Preisach model	79
Figure 4.6	Effect of varying swarm sizes	84
Figure 4.7	Effect of varying number of iterations	86
Figure 4.8	Force-displacement characteristics for interval current	88
Figure 4.9	Comparison results for input current of 0 A	92
Figure 4.10	Comparison results for input Current of 0.5 A	93
Figure 4.11	Comparison results for input current of 1.0 A	94
Figure 4.12	Comparison results for input current of 1.5 A	95
Figure 4.13	Comparison results for input current of 2.0 A	96
Figure 4.14	The force displacement curve for current 0.3 A and 0.7 A	98
Figure 4.15	The force displacement curve for current 1.3 A and 1.7 A	100

Figure 5.1	Full control design for the experiment testing	104
Figure 5.2	If then rule algorithm	106
Figure 5.3	Simulation results for active front bumper system with control design	108
Figure 5.4	Universal pendulum impact tester (Enkay Enterprises, 2023)	109
Figure 5.5	Pendulum impactor at different cases	110
Figure 5.6	Sled impactor	112
Figure 5.7	Scaled vehicle with weight load	113
Figure 5.8	Comparison of Froude number of model and prototype	115
Figure 5.9	Full collision test rig	116
Figure 5.10	LVDT sensor position	117
Figure 5.11	Accelerometer position	118
Figure 5.12	Experimental setup for active front bumper system	120
Figure 5.13	Acceleration and displacement response for light impact collision	123
Figure 5.14	Acceleration and displacement response for medium impact collision	125
Figure 5.15	Acceleration and displacement response for hard impact collision	128

LIST OF ABBREVIATIONS

ABS	-	Antilock Braking System
ACD	-	Actual Crash Data
ADAMS	-	ADAMS Multibody Model
ADAS	-	Advanced Driver Assistance Systems
AEB	-	Automatic Emergency Braking
BPF	-	Band Pass Frequency
CFRP	-	Carbon Fibre Reinforced Polymer
CIP	-	Carbonyl Iron particle
DOF	-	Degree of Freedom
E&E	-	Elkady and Elmarakbi Model
ECU	-	Electronic Control Unit
FCW	-	Forward Collision Warning
GFRP	-	Glass Fibre Reinforced Polymer
HPF	-	High Pass Frequency
IMC	-	Internal Model Control
LB	-	Lower Boundary
LPF	-	Low Pass Frequency
LVDT	-	Linear Variable Differential Transformer
MIROS	-	Malaysian Institute of Road Safety Research
MKM	-	Multiple Kelvin Model
MR	-	Magneto – Rheological
MRE	-	Magnetorheological Elastomer
MREBEARD	-	Adaptive Energy Absorption Device

MRF	-	Magneto – Rheological Fluid
PET	-	Polyethylene Terephthalate
PID	-	Proportional-Integral-Derivative
POM	-	Polyoxymethylene
PSO	-	Particle Swarm Optimization
PWM	-	Pulse Width Modulation
RMSE	-	Root Mean Square Error
RTV	-	Room Temperature Vulcanization
UB	-	Upper Boundary
UPNM	-	Universiti Pertahanan Nasional Malaysia
VTB	-	Vehicle to Barrier
VTV	-	Vehicle to Vehicle

LIST OF SYMBOLS

c	-	Damper Coefficient
C_l	-	Skyhook Damper Coefficient
F	-	Impact Force
F_d	-	Force Desired
F_r	-	Froude Number
g	-	Gravitational Acceleration
iw	-	Inertia weight
k	-	Spring Constant
K	-	Potential Energy
K_d	-	Derivative Value
K_i	-	Integral Value
K_p	-	Proportional Value
L	-	Length of Vehicle
N_i	-	Number of Iterations
N_p	-	Number of Particles
Q	-	Dissipative Energy
T	-	Kinetic Energy

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	: Results	146
Appendix B	: Coding	150
Appendix C	: Calculations	155
Appendix D	: Specifications of Sensors	159
Appendix E	: Drawings	162

CHAPTER 1

INTRODUCTION

1.1 Background Study

Road safety remains a significant national concern in Malaysia, with an increase in road accident cases to approximately 53,000 in 2022. Tragically, these incidents have resulted in the loss of over 12,000 lives, as reported by The Sun (The Sun, 2024). One major contributing factor to these accidents is the design of the bumper beam. They are designed with a conventional bumper beam that is less efficient in terms of absorbing the total amount of energy during a frontal collision. This conventional bumper beam is constructed from hard composites and can only absorb a small amount of impact energy. Furthermore, this type of bumper does not actively reduce the impact force and is designed to withstand low-speed collisions where the impact force is minimal. Consequently, this design flaw often leads to unnecessary vehicle damage during collisions.

Therefore, this study is focused on improving the safe protection of the occupants from the frontal collision by introducing an active front bumper system employing Magnetorheological Elastomer (MRE) dampers positioned between the chassis and the front bumper. MRE is a well-known material that has the capability to

adjust its stiffness and damping coefficients with the applied currents injected to the material. Initially, a mathematical model representing an actual vehicle crumple zone is developed to examine which part of the vehicle affected during frontal collision (Amin et al., 2017; Ramamurthy et al., 2018).

Moreover, a simulation model is developed to simulate the impact behaviour of Magnetorheological Elastomer aiming to characterize its force-displacement during impact collision. Next, the proposed model undergoes validation through comparison with experimental results obtained from a drop impact test by comparing the force displacement characteristics with the different applied current. Both validated models are then used in the control strategy to evaluate the active front bumper system.

The control strategy implemented in this study analyses the system's response in three responses which are displacement, acceleration, and transmitted force using the hybrid controller. This evaluation is then continued with the fabrication of a collision test rig that represents the active front bumper system. The experiment is conducted at different cases such as passive, active, and off state to evaluate the active front bumper system in reducing the effect of frontal collision than compared with the simulation result (Sethi M.K. & Kumar A, 2016; Leng D et al., 2017).

1.2 Problem Statement

Road accident cases have shown an increase about 175,000 cases from 2021 to 2022, particularly involving frontal vehicle collisions compared to rear and side collisions (The Star, 2023). This trend can be attributed to the conventional bumper