PERFORMANCE OF SEMI-ACTIVE CONTROL OF RAILWAY VEHICLE SUSPENSION

MOHAMAD FAIZUL FADZLY BIN SALEHUDIN

This report is represented in
partial fulfillment of the requirement for the
Degree of Bachelor of Mechanical Engineering (Automotive)

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

MAY 2011

© Universiti Teknikal Malaysia Melaka

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for award of degree of Bachelor of Mechanical Engineering (Automotive)."

Signature	:……
Supervisor I	: Mr. Mohd Hanif Bin Harun
Date	: 23 May 2011

Signature	:……
Supervisor II	: Mr. Fauzi Bin Ahmad
Date	: 23 May 2011

© Universiti Teknikal Malaysia Melaka

"I hereby declare that the work in this report is my own work except for summaries and quotations that I have mentioned its sources."

Signature :…….

Name of Author : Mohamad Faizul Fadzly Bin Salehudin

Date : 23 May 2011

© Universiti Teknikal Malaysia Melaka

To my beloved dad, mom and family

© Universiti Teknikal Malaysia Melaka

ACKNOWLEDGEMENTS

I would like to offer my heartfelt thanks to Projek Sarjana Muda (PSM) Committee, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) concerned for having an arrangement of PSM for all fourth year students and giving us an invaluable chance to involve in PSM. My PSM supervisor, Mr. Mohd. Hanif bin Harun contributed a great amount of time and effort for making this PSM a success. He is willing to sacrifice their time and energy to discuss with me about my PSM research "Performance of Semi-Active Control of Railway Vehicle Suspension" during PSM period.

Meanwhile, I would like to offer heartfelt thanks to my course mate in Bachelor of Mechanical Engineering (Automotive) programme who has been helpful. They also give professional guidance, constructive comments and ideas to me during finishing this PSM.

I would be remiss and even be ungrateful if I could not acknowledge the help given to me by my family members. They are always a deep love and strong sense of encouragement from them. I hope my effort which done for PSM will be meaningful to each of them. Besides that, I also would like to offer my heartfelt thanks to everyone who involved directly and indirectly in this PSM research.

© Universiti Teknikal Malaysia Melaka

To all of you, whom I mentioned above, please accept my deepest thanks. With your concern, I have successfully completed the PSM research within the stipulated period. Thank you all.

© Universiti Teknikal Malaysia Melaka

ABSTRACT

This PSM report describe the performance of semi-active control of railway vehicle suspension. The overall PSM work including development of 3 degree of freedom (DOF) of half railway vehicle ride model, equation of motion for passive suspension control and semi-active suspension control, PID controller for semi-active suspension control, half railway vehicle ride model with passive suspension control, half railway vehicle ride model with semi-active suspension control and simulate both half railway vehicle ride model with MATLAB-Simulink. The PSM work also study and analyze several graphs from simulation work for half railway vehicle ride model such as body acceleration, body velocity, body displacement, body rolling acceleration, body rolling velocity, body rolling angle, bogie acceleration, bogie velocity, bogie displacement, suspension travel response for damper (Cs), suspension travel response for spring (k1) and suspension travel response for spring (k3). The discussion is including evaluate the performance of semi-active suspension control with the passive suspension control of half railway vehicle ride model according to the graphs from simulation results. Based on analysis and discussion, the semi-active suspension control has provided the improved performance compared with the passive suspension control for half railway vehicle ride model.

© Universiti Teknikal Malaysia Melaka

ABSTRAK

Laporan PSM ini menerangkan prestasi kawalan semi aktif untuk suspensi kenderaan kereta api. Kerja-kerja untuk keseluruhan PSM adalah meliputi pembangunan 3 darjah kebebasan untuk model separuh kenderaan kereta api dalam keadaan bergerak, persamaan gerakan untuk kawalan suspensi pasif and kawalan suspensi semi aktif, pengawal PID untuk kawalan suspensi semi aktif, model separuh kenderaan kereta api dalam keadaan bergerak dengan kawalan suspensi pasif, model separuh kenderaan kerata api dalam keadaan bergerak dengan kawalan suspensi semi aktif dan menjalankan simulasi untuk kedua-dua model separuh kenderaan kereta api dengan menggunakan perisian komputer yang dikenali sebagai „MATLAB-Simulink". Kerja PSM ini akan mengkaji dan menganalisis beberapa graf iaitu pecutan jasad, halaju jasad, sesaran jasad, pecutan gulingan jasad, halaju gulingan jasad, sudut gulingan jasad pecutan bogi, halaju bogi, sesaran bogi, tindak balas perjalanan suspensi untuk penyerap hentakan (Cs), tindak balas perjalanan suspensi untuk spring (k1), tindak balas perjalanan dan tindak balas perjalanan suspensi untuk spring (k3). Hasil analisis dan perbincangan menunjukkan bahawa kawalan suspensi semi aktif memberikan peningkatan prestasi berbanding kawalan suspensi pasif untuk model separuh kenderaan kereta api.

© Universiti Teknikal Malaysia Melaka

CONTENTS

CHAPTER	TITLE	PAGE
	SUPERVISOR DECLARATION	ii
	DECLARATION	iii
	DEDICATION	iv
	ACKNOWLEDGMENTS	v
	ABSTRACT	vii
	ABSTRAK	viii
	CONTENTS	ix
	LIST OF FIGURES	xv
	LIST OF TABLES	xxiii
	LIST OF SYMBOLS	xxiv
	LIST OF ABBREVIATION	xxvi
	LIST OF APPENDICES	xxvii

© Universiti Teknikal Malaysia Melaka

CHAPTER I	**INTRODUCTION**		1
	1.1	Background	1
	1.2	Problem Statement	2
	1.3	Project Objective	4
	1.4	Project Scope	4
	1.5	Project Gantt Chart	5
	1.6	Project Outline	8
	1.7	Project Flow Chart	9
CHAPTER II	**LITERATURE REVIEW**		10
	2.1	Theory	10
	2.2	Suspension System	11
		2.2.1 Passive Suspension System	12
		2.2.2 Active Suspension System	13
		2.2.3 Semi-Active Suspension System	15
	2.3	Overview Of Railway Vehicle	16
		2.3.1 Study Of Semi-Active Suspension For Railway Vehicle Suspension	17
		2.3.2 Study Of Semi-Active Control	20
		(A) PID Controller	20
		(B) PID Controller Design In Semi-Active Suspension System	23
CHAPTER III	**METHODOLOGY**		27
	3.1	Project Methodology	28
	3.2	3 DOF Of Half Railway Vehicle Model	30
		3.2.1 Equation Of Motion For Passive Suspension System	31
		(A) Free Body Diagram For Bogie	33

© Universiti Teknikal Malaysia Melaka

(B) Free Body Diagram For Body 33
(C) Free Body Diagram For Roll Case 34
(D) Equation And Parameters 35
3.2.2 Equation Of Motion For Semi-Active Suspension System 36
(A) Free Body Diagram For Bogie 38
(B) Free Body Diagram For Body 38
(C) Free Body Diagram For Roll Case 39
(D) Equation And Parameters 40

CHAPTER IV RESULT AND ANALYSIS 41
4.1 Result And Analysis For PSM Work 41
4.2 Block Diagram Of Passive, Semi-Active, Skyhook And Groundhook Suspension System 42
4.2.1 Subsystem For Passive Suspension System 44
4.2.2 Equation Of Motion For Passive Suspension System 45
4.2.3 Simulation Parameter For Passive Suspension System 45
4.2.4 Subsystem For Semi-Active Suspension System 46
4.2.5 Equation Of Motion For Semi-Active Suspension System 47
4.2.6 Simulation Parameter For Semi-Active Suspension System 47
4.2.7 Subsystem For Skyhook Suspension System 48
4.2.8 Equation Of Motion For Skyhook Suspension System 49

© Universiti Teknikal Malaysia Melaka

	4.2.9	Simulation Parameter For Skyhook Suspension System	49
	4.2.10	Subsystem For Groundhook Suspension System	50
	4.2.11	Equation Of Motion For Groundhook Suspension System	51
	4.2.12	Simulation Parameter For Groundhook Suspension System	51
4.3	Graph Result And Analysis From Simulation Work		52
	4.3.1	Graph Of Body Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System	53
	4.3.2	Graph Of Body Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System	55
	4.3.3	Graph Of Body Lateral Displacement For Passive, Semi-Active, Skyhook And Groundhook Suspension System	56
	4.3.4	Graph Of Body Rolling Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System	58
	4.3.5	Graph Of Body Rolling Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System	60
	4.3.6	Graph Of Body Rolling Angle For Passive, Semi-Active, Skyhook And Groundhook Suspension System	62
	4.3.7	Graph Of Bogie Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System	63

© Universiti Teknikal Malaysia Melaka

	4.3.8	Graph Of Bogie Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System	65
	4.3.9	Graph Of Bogie Lateral Displacement For Passive, Semi-Active, Skyhook And Groundhook Suspension System	67
	4.3.10	Graph Of Suspension Travel Response For Damper (Cs) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System	68
	4.3.11	Graph Of Suspension Travel Response For Spring (k1) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System	70
	4.3.12	Graph Of Suspension Travel Response For Spring (k3) Of Passive, Semi-Active, Skyhook And Groundhook Suspension	72
CHAPTER V	**DISCUSSION**		74
	5.1	Discussion For PSM Work	74
	5.2	Validation Of Graphs From Simulation Work	75
	5.2.1	Body Lateral Acceleration	76
	5.2.2	Body Rolling Acceleration	81
	5.2.3	Suspension Travel Response For Spring (k1)	85
	5.2.4	Suspension Travel Response For Spring (k3)	89
	5.2.5	Body Lateral Velocity	93
	5.2.6	Body Lateral Displacement	95
	5.2.7	Body Rolling Velocity	97

© Universiti Teknikal Malaysia Melaka

	5.2.8	Body Rolling Angle	99
	5.2.9	Bogie Lateral Acceleration	101
	5.2.10	Bogie Lateral Velocity	103
	5.2.11	Bogie Lateral Displacement	105
	5.2.12	Suspension Travel Response For Damper (Cs)	107
CHAPTER VI	**CONCLUSION AND RECOMMENDATION**		109
	6.1	Conclusion And Recommendation For PSM Work	109
	REFERENCES		112
	APPENDICES		116

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES

NO.	TITLE	PAGE
Figure 1.1	Project Flow Chart	9
Figure 2.1	Passive Suspension System	13
Figure 2.2	Schematic Diagram Of An Active Suspension System	14
Figure 2.3	Schematic Diagram Of A Semi-Active Suspension System	16
Figure 2.4	Railway Vehicle	17
Figure 2.5	Railway Vehicle Suspension System	19
Figure 2.6	Railway Vehicle Suspension System	19
Figure 2.7	A Block Diagram Of A PID Controller	21
Figure 2.8	Semi-Active Suspension System Model	24
Figure 2.9	Block Diagram For Semi-Active Suspension With PID Controller	26

© Universiti Teknikal Malaysia Melaka

Figure 3.1	3 DOF Of Half Railway Vehicle Model For Simulation Work	30
Figure 3.2	Half Railway Vehicle Ride Model For Passive Suspension System	31
Figure 3.3	Free Body Diagram For Bogie Of Passive Suspension System	33
Figure 3.4	Free Body Diagram For Body Of Passive Suspension System	33
Figure 3.5	Free Body Diagram For Roll Case Of Passive Suspension System	34
Figure 3.6	Half Railway Vehicle Ride Model For Semi-Active Suspension System	36
Figure 3.7	Free Body Diagram For Bogie Of Semi-Active Suspension System	38
Figure 3.8	Free Body Diagram For Body Of Semi-Active Suspension System	38
Figure 3.9	Free Body Diagram For Roll Case Of Semi-Active Suspension System	39
Figure 4.1	Block Diagram Of MATLAB-Simulink Of Passive, Semi-Active, Skyhook And Groundhook Suspension System	43
Figure 4.2	Subsystem For Passive Suspension System	44
Figure 4.3	Subsystem For Semi-Active Suspension System	46
Figure 4.4	Subsystem For Skyhook Suspension System	48
Figure 4.5	Subsystem For Groundhook Suspension System	50

© Universiti Teknikal Malaysia Melaka

Figure 4.6	Graph Of Body Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System	53
Figure 4.7	Graph Of Body Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System	55
Figure 4.8	Graph Of Body Lateral Displacement For Passive, Semi-Active, Skyhook And Groundhook Suspension System	56
Figure 4.9	Graph Of Body Rolling Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System	58
Figure 4.10	Graph Of Body Rolling Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System	60
Figure 4.11	Graph Of Body Rolling Angle For Passive, Semi-Active, Skyhook And Groundhook Suspension System	62
Figure 4.12	Graph Of Bogie Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System	63
Figure 4.13	Graph Of Bogie Lateral Velocity For Passive, Semi-Skyhook And Groundhook Suspension System	65
Figure 4.14	Graph Of Bogie Lateral Displacement For Passive, Semi-Active, Skyhook And Groundhook Suspension System	67
Figure 4.15	Graph Of Suspension Travel Response For Damper (Cs) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System	68

© Universiti Teknikal Malaysia Melaka

Figure 4.16	Graph Of Suspension Travel Response For Spring (k1) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System	70
Figure 4.17	Graph Of Suspension Travel Response For Spring (k3) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System	72
Figure 5.1	Graph Of Body Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	76
Figure 5.2	Graph Of Locomotive Lateral Acceleration Versus Time With Random Railway Track Profile	77
Figure 5.3	Graph Of Body Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	78
Figure 5.4	Graph Of Body Lateral Acceleration Versus Frequency For Passive And Semi-Active Suspension System	79
Figure 5.5	Graph Of Body Lateral Acceleration Versus Frequency For Passive And Semi-Active Suspension System From Gao, G. S. and Yang, S. P. (2006)	79
Figure 5.6	Graph Of Body Rolling Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	81
Figure 5.7	Graph Of Body Rolling Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	82

© Universiti Teknikal Malaysia Melaka

Figure 5.8	Graph Of Body Rolling Acceleration Versus Frequency For Passive And Semi-Active Suspension System	83
Figure 5.9	Graph Of Body Rolling Acceleration Versus Frequency For Passive And Semi-Active Suspension System From Gao, G. S. and Yang, S. P. (2006)	83
Figure 5.10	Graph Of Suspension Travel Response For Spring (k1) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	85
Figure 5.11	Graph Of Suspension Travel Response For Spring (k1) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	86
Figure 5.12	Graph Of Suspension Travel Response For Spring (k1) Versus Frequency For Passive And Semi-Active Suspension System	87
Figure 5.13	Graph Of Suspension Travel Response Versus Frequency For Passive And Semi-Active Suspension System From Gao, G. S. and Yang, S. P. (2006)	87
Figure 5.14	Graph Of Suspension Travel Response For Spring (k3) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	89
Figure 5.15	Graph Of Suspension Travel Response For Spring (k3) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	90

© Universiti Teknikal Malaysia Melaka

Figure 5.16	Graph Of Suspension Travel Response For Spring (k3) Versus Frequency For Passive And Semi-Active Suspension System	91
Figure 5.17	Graph Of Suspension Travel Response Versus Frequency For Passive And Semi-Active Suspension System From Gao, G. S. and Yang, S. P. (2006)	91
Figure 5.18	Graph Of Body Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	93
Figure 5.19	Graph Of Body Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	94
Figure 5.20	Graph Of Body Lateral Displacement For Passive Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	95
Figure 5.21	Graph Of Body Lateral Displacement For Passive Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	96
Figure 5.22	Graph Of Body Rolling Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	97
Figure 5.23	Graph Of Body Rolling Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	98
Figure 5.24	Graph Of Body Rolling Angle For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	99

© Universiti Teknikal Malaysia Melaka

Figure 5.25	Graph Of Body Rolling Angle For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	100
Figure 5.26	Graph Of Bogie Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	101
Figure 5.27	Graph Of Bogie Lateral Acceleration For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	102
Figure 5.28	Graph Of Bogie Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusiodal Railway Track Profile	103
Figure 5.29	Graph Of Bogie Lateral Velocity For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	104
Figure 5.30	Graph Of Bogie Lateral Displacement For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	105
Figure 5.31	Graph Of Bogie Lateral Displcement For Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	106
Figure 5.32	Graph Of Suspension Travel Response For Damper (Cs) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System With Sinusoidal Railway Track Profile	107

© Universiti Teknikal Malaysia Melaka

Figure 5.33	Graph Of Suspension Travel Response For Damper (Cs) Of Passive, Semi-Active, Skyhook And Groundhook Suspension System With Random Railway Track Profile	108

© Universiti Teknikal Malaysia Melaka

LIST OF TABLES

NO.	TITLE	PAGE
Table 1.1	Project Gantt Chart	5
Table 2.1	Effect Of Independent P, I And D Tuning	23
Table 2.2	Symbol For Semi-Active Suspension System	25

© Universiti Teknikal Malaysia Melaka

LIST OF SYMBOLS

m_1	=	Bogie Mass, kg
m_2	=	Body Mass, kg
I_r	=	Moment Of Inertia Of Rolling, $kg.m^2$
k_1	=	Spring Stiffness, N/m
k_2	=	Spring Stiffness, N/m
k_3	=	Spring Stiffness, N/m
b	=	Half Of Track Width (Distance Between k_3 And Centre Of Gravity Of Body), m
h_1	=	Height Between k_1 And Centre Of Gravity Of Body, m
h_2	=	Height Between c_s And Centre Of Gravity Of Body, m
c_s	=	Damping Coefficient, Ns/m
Θ	=	Roll Angle At The Centre Of Gravity Of Body, ˚
$\ddot{\Theta}$	=	Roll Acceleration At The Centre Of Gravity Of Body, rad/s^2
F_{s1}	=	Spring Force, N
F_{s2}	=	Spring Force, N

© Universiti Teknikal Malaysia Melaka