

“I hereby declare that I have read through this report entitle “*Analysis on Passive Vehicle Suspension System*” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)”

Signature :

Supervisor name : Dr. Aliza Bte Che Amran
.....

Date : 18/6/2014
.....

ANALYSIS ON PASSIVE VEHICLE SUSPENSION SYSTEM

CHIN FEN YING

**A report submitted in partial fulfillment of the requirements for the degree of Bachelor
in Electrical Engineering (Control, Instrumentations and Instrumentations)**

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitle “*Analysis on Passive Vehicle Suspension System*” is the result of my own research except as cited in references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Chin Fen Ying
.....

Date : 17/6/2014
.....

ACKNOWLEDGMENT

It is a pleasure to thank those who made this thesis possible. I would like to acknowledge and extend my heartfelt gratitude to my supervisor, Dr Aliza Binti Che Amran for her vital encouragement and support. This thesis would not have been possible to be completed if without her valuable guidance regarding the production of this thesis. Her ideas, suggestions, advices and guidance have really helped me to improve and understand more on the objectives of the thesis.

In addition, I would like to say thanks for all master students of Motion Control Lab who taught me about OriginPro 8, Matlab Simulink and MicroBox 2000/2000C. Last but not least, I would also like to thank my course mates, for the help and inspiration extended during the whole period. They have made available their support in a number of ways. For instance, they had been constantly given suggestions and assistance for the completion of the thesis.

ABSTRACT

Vehicle suspension system plays an important role in automobile industry in order to guarantee good ride quality of vehicle. Basically, traditional suspension system which is passive suspension system consists of springs, shock absorbers and linkages that connect a vehicle body to its wheels. However, passive suspension system is an open loop system which does not contain any controllers to control the performance of the vehicle suspension system when passing through bumpy on the road. In this report, construction of an experiment setup to represent passive vehicle suspension system for quarter car model is considered. Experimental setup for passive suspension system is important because proper modeling of vehicle suspension system could lead to good controller design and hence improve the performance of the vehicle suspension system. This report primarily focuses on the two-degree-of freedom quarter-car model to represent passive suspension system. Semi-active and active suspension system will not be covered in this project. A number of experiments have been carried out using the experiment setup in order to identify the characteristic of this experimental setup. Experiments with different vehicle body mass, different period for one pulse and different pulse width of input pressure of the road excitation have been conducted. The experiments results are evaluated based on the vehicle body displacement and tire displacement of the experimental setup. However, experiments give different results when three parameters are varied. Experiment results show that the pulse width of the input pressure is directly affected the characteristic of this passive suspension system experimental setup. Lastly, simple simulation has been done in order to compare the simulation and experiments results. The amplitude and shape of the simulation and experimental results are evaluated in this report.

ABSTRAK

Sistem kenderaan memainkan peranan penting bagi menjamin kualiti perjalanan kenderaan yang baik. Pada asasnya, sistem suspensi tradisional yang merupakan sistem suspensi pasif terdiri daripada spring, penyerap henjutan yang menghubungkan kenderaan dan roda . Walau bagaimanapun, sistem suspensi pasif ialah sistem gelung terbuka yang tidak mengandungi apa-apa pengawal untuk mengawal prestasi sistem kenderaan apabila melalui permukaan jalan raya yang beralun. Oleh itu, pembinaan sebuah setup eksperimen untuk mewakili sistem kenderaan pasif untuk suku model kereta telah dipertimbangkan. Penyediaan eksperimen sistem pasif adalah penting kerana pemodelan baik sistem suspensi kenderaan boleh membawa kepada reka bentuk pengawal yang baik dan dengan itu meningkatkan prestasi sistem penggantungan kenderaan. Laporan ini memberi tumpuan terutama kepada dua darjah kebebasan model suku – kereta untuk mewakili sistem suspensi pasif. Sistem suspensi separuh-aktif dan aktif tidak akan termasuk dalam projek ini Beberapa eksperimen telah dijalankan dengan menggunakan setup eksperimen untuk mengenal pasti ciri setup eksperimen ini. Eksperimen dengan jisim kereta yang berbeza dan tekanan input berbeza lebar denyut telah dijalankan. Keputusan eksperimen dinilai berdasarkan anjakan badan kenderaan dan anjakan tayar. Tetapi, keputusan eksperimen akan berubah apabila tiga parameter berdasarkan eksperimen set dimanipulasi. Saiz input tekanan secara langsung memberi kesan kepada ciri bagi sistem suspensi pasif persediaan eksperimen ini.. Akhir sekali, simulasi telah dilakukan untuk membandingkan keputusan simulasi dan eksperimen. Amplitud dan bentuk keputusan simulasi dan eksperimen telah dinilai dalam laporan ini

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii-ix
	LIST OF TABLES	x
	LIST OF FIGURES	xi-xiv
	LIST OF ABBREVIATIONS	xv
	LIST OF APPENDIX	xvi-xvii
1	INTRODUCTION	
	1.1 Research Background	1-4
	1.2 Research Motivation	4-5
	1.3 Objectives	6
	1.4 Scope of Research	6
2	LITERATURE REVIEW	
	2.1 Basic principles	7
	2.1.1 Passive Suspension System	8
	2.1.2 Semi-active Suspension System	8
	2.1.3 Active Suspension System	8
	2.1.4 Advantages and Disadvantages of Each Suspension System	9
	2.2 Others Research and Studies	9-12
	2.3 Summary of review	12-13

3**METHODOLOGY**

3.1	Experimental Hardware and Setup	14-18
3.1.1	Equipments Used In Experiment Setup	19
3.1.1.1	Micro-Box 2000/2000C	19
3.1.1.2	Arduino Mega 2560 R3	20
3.1.1.3	Ball Bearing	20-21
3.1.1.4	Infrared Sensor (IR-sensor)	22-24
3.1.1.5	Spring	24-27
3.1.1.6	Gas Spring	27-30
3.1.1.7	Pneumatic Double Acting Cylinder	30-31 31-32
3.1.1.8	Flow Control Valve	32-34
3.1.1.9	Pressure Regulator	33-34
3.1.1.10	Single Solenoid Valve 5/2 Way	34
3.1.1.11	Air Compressor	35-38
3.2	Development of Quarter Car Model	
3.2.1	Derivation of Mathematical Model Quarter Car Passive Suspension System	35-37 38
3.2.2	Simulink Model in Matlab	

4**RESULTS ANALYSIS AND DISCUSSIONS**

4.1	Calibration Results for Experimental Equipments	39
4.1.1	Infrared Sensor Calibration Result	39-41
4.1.2	Gas Spring Calibration Result	42
4.1.3	Spring Calibration Result	
4.1.3.1	Spring Places between Mass of Vehicle Body and Tire	43
4.1.3.2	Spring Represents the Air Pressure inside Tire	44
4.2	Repeatability	45-46
4.2.1	Repeatability Test with Mass of Vehicle	47-49

	Body = 4.29kg	
4.2.2	Repeatability Test with Mass of Vehicle	50-52
	Body = 4.59kg	
4.2.3	Repeatability Test with Mass of Vehicle	53-55
	Body = 4.79kg	
4.3	Experiments with Different Mass and Different Input	56-68
4.4	Simulation and Experimental Results Analysis and Discussion	69-78
5	CONCLUSION AND FUTURE WORKS	79-80
	REFERENCES	81-83
	APPENDIX	84-101

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Dimensions of the experimental setup	15
3.2	Calibration equation of equipments used in experimental setup.	18
3.3	System parameters for passive suspension system.	36
4.1	Data array	45
4.2	Types of experiments.	56
4.3	Dynamic response of Experiment A.	58
4.4	Dynamic response of Experiment B.	60
4.5	Dynamic response of Experiment C.	61
4.6	Dynamic response of Experiment D.	63
4.7	Parameters used in experimental and simulation process	69

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1(a)	Bad road quality in Malaysia	2
1.1(b)	Pothole on the road surface in Malaysia	2
1.2(a)	Diagram of spring and shock absorber	2
1.2(b)	How absorber and spring are attached to a vehicle	2
1.3(a)	Passive suspension system	4
1.3(b)	Semi-active suspension system	4
1.3(c)	Active suspension system	4
1.4	Suspension travel and wheel deflection	5
2.1	Active suspension system	13
3.1	Schematic diagram of experimental setup	16
3.2	Experimental setup	17
3.3	Micro-Box 2000/2000C	19
3.4	Arduino Mega 2560 R3	20
3.5	A bearing	21
3.6	Bearing assembly on one of the plates	21
3.7	Infrared sensor	23
3.8(a)	Calibration of sensor at 1cm	23
3.8(b)	Calibration of sensor at 23cm	23
3.9	Simulink block diagram used to display the reading of the output voltage when the sensor is adjusted to certain displacement	24
3.10	Schematic diagram of how to determine the length of spring when it is compressed away by force (F)	25
3.11	Experimental setup used to get the spring constant of a spring	26
3.12	Experiment setup to record the time taken for the piston rod of gas spring to extend after being compressed	29

3.13	Experiment setup for obtaining the length of the piston rod when load is added to the gas spring	30
3.14	Double acting cylinder	31
3.15	Flow control valve	32
3.16	Pressure regulator	33
3.17	Schematic symbol of single solenoid valve 5/2 way	33
3.18	Single solenoid valve 5/2 way	34
3.19	Air compressor	34
3.20	Schematic diagram of quarter car	36
3.21	Free body diagram	36
3.22	Designed simulink model of the passive suspension system in MATLAB	38
4.1	Infrared sensor calibration result of output voltage (V) versus displacement (mm)	40
4.2	Infrared sensor calibration result of output voltage (V) versus inverse number of displacement (mm)	41
4.3	Gas spring calibration result of force (N) versus velocity (m/s)	42
4.4	Spring places between mass of vehicle body and tire calibration result of force (N) versus length of spring being compressed (m)	43
4.5	Spring represents the air pressure inside tire calibration result of force (N) versus length of spring being compressed (m)	44
4.6	Repeatability test result of vehicle body displacement with mass = 4.29kg	47
4.7	Repeatability test result of vehicle body velocity with mass = 4.29kg	47
4.8	Repeatability test result of vehicle body acceleration with mass = 4.29k	48
4.9	Repeatability test result of suspension travel with mass = 4.29kg	48
4.10	Repeatability test result of tire displacement with mass = 4.29kg	49
4.11	Repeatability test result of wheel deflection with mass = 4.29kg	49
4.12	Repeatability test result of vehicle body displacement with mass	50

	= 4.59kg	
4.13	Repeatability test result of vehicle body velocity with mass = 4.59kg	50
4.14	Repeatability test result of vehicle body acceleration with mass = 4.59kg	51
4.15	Repeatability test result of suspension travel with mass = 4.59kg	51
4.16	Repeatability test result of tire displacement with mass = 4.59kg	52
4.17	Repeatability test result of wheel deflection with mass = 4.59kg	52
4.18	Repeatability test result of vehicle body displacement with mass = 4.79kg	53
4.19	Repeatability test result of vehicle body velocity with mass = 4.79kg	53
4.20	Repeatability test result of vehicle body acceleration with mass = 4.79kg	54
4.21	Repeatability test result of suspension travel with mass = 4.79kg	54
4.22	Repeatability test result of tire displacement with mass = 4.79kg	55
4.23	Repeatability test result of wheel deflection with mass = 4.79kg	55
4.24	Vehicle body displacement of Experiment A	57
4.25	Vehicle body displacement of Experiment B	57
4.26	Vehicle body displacement of Experiment C	57
4.27	Vehicle body displacement of Experiment D	57
4.28	Vehicle body displacement of Experiment A using different vehicle body mass	58
4.29	Vehicle body displacement of Experiment B using different vehicle body mass.	60
4.30	Vehicle body displacement of Experiment C using different vehicle body mass	61
4.31	Vehicle body displacement of Experiment D using different vehicle body mass	63
4.32	Tire displacement of Experiment A	65
4.33	Tire displacement of Experiment B	65

4.34	Tire displacement of Experiment C	65
4.35	Tire displacement of Experiment D	65
4.36	Tire displacement of Experiment A using different vehicle body mass	66
4.37	Tire displacement of Experiment B using different vehicle body mass.	67
4.38	Tire displacement of Experiment C using different vehicle body mass	67
4.39	Tire displacement of Experiment D using different vehicle body mass	68
4.40	Pulse input signal used during simulation and experimental process.	70
4.41	Pulse input signal with filter during experimental process.	72
4.42	Vehicle body displacement of simulation and experimental result.	73
4.43	Vehicle body velocity of simulation and experimental result	73
4.44	Vehicle body acceleration of simulation and experimental result.	74
4.45	Tire displacement of simulation and experimental result.	75
4.46	Suspension travel of simulation and experimental result.	75
4.47	Wheel deflection of simulation and experimental result.	76

LIST OF ABBREVIATIONS

M_s	-	Mass of vehicle body (sprung mass)
M_{us}	-	Mass of the wheel and tire (unsprung mass)
k_s	-	Spring constant of the suspension system
k_t	-	Spring constant of the tire
b_s	-	Dashpot constant (shock absorber)
r	-	Vertical displacement of road input
X_s	-	Vertical displacement of sprung mass
X_{us}	-	Vertical displacement of unsprung mass

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Experimental Setup Equipments Calibration Results	
	Table A1 Infrared sensor calibrated result	84
	Table A2 Gas spring calibration result of length of piston rod collected when load is added to the gas spring	85
	Table A3 Damping coefficient of gas spring at different force and velocity	86
	Table A4 Calibration result of spring places between mass of vehicle body and tire	87
	Table A5 Calibration result of spring represents the air pressure inside tire	87
B	Draft of Experimental Setup	
	Figure B1 First draft for the prototype of the passive suspension system	88
	Figure B2 Second draft for the prototype of the passive suspension system	88
	Figure B3 Failed experimental setup	89
C	Graphs of Experiments	
	Figure C1 Vehicle body displacement of Experiment A.	90
	Figure C2 Vehicle body velocity of Experiment A.	90
	Figure C3 Vehicle body acceleration of Experiment A.	91
	Figure C4 Suspension travel of Experiment A	91
	Figure C5 Tire displacement of Experiment A.	92
	Figure C6 Wheel deflection of Experiment A.	92
	Figure C7 Vehicle body displacement of Experiment B.	93
	Figure C8 Vehicle body velocity of Experiment B.	93

Figure C9	Vehicle body acceleration of Experiment B.	94
Figure C10	Suspension travel of Experiment B.	94
Figure C11	Tire displacement of Experiment B.	95
Figure C12	Wheel deflection of Experiment B.	95
Figure C13	Vehicle body displacement of Experiment C.	96
Figure C14	Vehicle body velocity of Experiment C.	96
Figure C15	Vehicle body acceleration of Experiment C.	97
Figure C16	Suspension travel of Experiment C.	97
Figure C17	Tire displacement of Experiment C.	98
Figure C18	Wheel deflection of Experiment C.	98
Figure C19	Vehicle body displacement of Experiment D.	98
Figure C20	Vehicle body velocity of Experiment D.	99
Figure C21	Vehicle body acceleration of Experiment D.	100
Figure C22	Suspension travel of Experiment D.	100
Figure C23	Tire deflection of Experiment D.	101
Figure C24	Wheel deflection of Experiment D.	101

CHAPTER 1

INTRODUCTION

The purpose of this chapter is to provide an introduction about the project carried out in this course. First of all, an overview of vehicle suspension system is being introduced. Then, problem statement of this project is explained. Next, project objectives and scopes are discussed at the end of this chapter.

1.1 Research Background

Nowadays, condition of local roads in Malaysia is getting worst. Roads are full of potholes, improper road shoulders and bumps. This condition causes a lot of problems especially damage to vehicles' parts and system where the potential damage includes tire puncture, premature wear on shocks and struts, wheel rim damage, suspension damage, steering system misalignment and engine damage. Moreover, those dreadful road conditions will affect drive stability, steering and braking which will lead to road accident. For example, a broken shock or strut which caused by severe hitting of a deep pothole could alter the steering and handling of the vehicle and create dangerous driving. This situation highlights that quality of road surface is very important in ensuring safe driving on the road. Besides that, good suspension system will increase the protection of vehicles from bad road conditions and hence decreases the rate of accidents in our country. In the above mentioned case, good suspension system will helps the vehicle to “absorb” the impact of the pothole thus the driving quality is not interrupted by bad road surfaces. Figure 1.1 shows the road conditions in Malaysia.



Figure 1.1: (a) Bad road quality in Malaysia [19] and (b) Pothole on the road surface in Malaysia [18]

Vehicle suspension system plays an important role in automobile industry in order to guarantee good quality of car. A good vehicle suspension system provides high vehicle handling, good drive stability, ensures the comfort of passengers, and good isolation from road noise, road shocks and vibration. Suspension system consists of springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two [16]. In other words, the suspension system separates the car body and the car wheel. The shock absorber dissipates shock energy received from road bump without causing undue oscillation in the vehicle. However, the spring absorbs the shock energy received from road bump and converts it into potential energy of spring. Figure 1.2 shows an example of a spring and shock absorber.

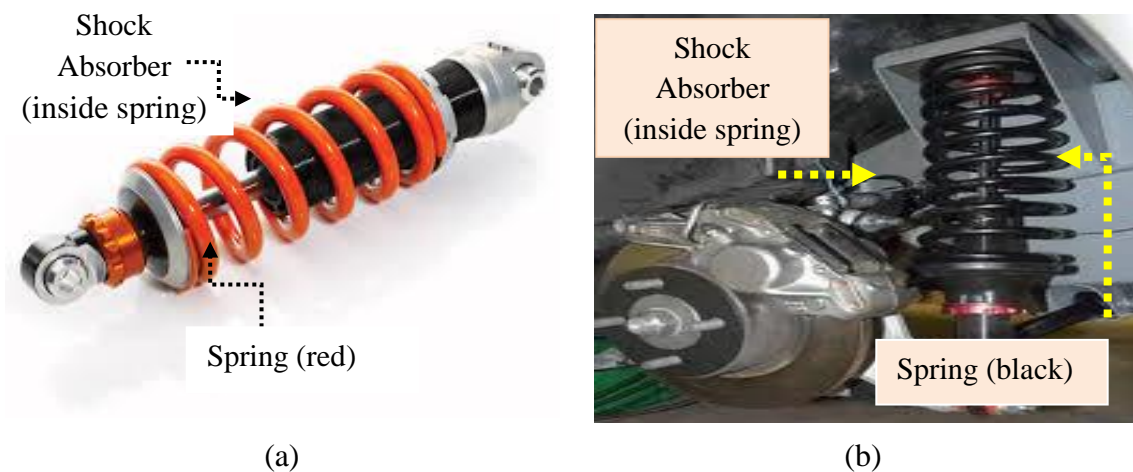


Figure 1.2: (a) Diagram of spring and shock absorber [20], and (b) How absorber and spring are attached to a vehicle [21]

The suspension systems can be divided into three types which are passive, semi-active, and active suspension system. The passive suspension system is an open-loop control system that does not contain any external energy sources and only consists of passive elements which are spring and shock absorber. Due to open-loop control system characteristic, the performance of the passive suspension system cannot be adjusted to achieve the desired performance. Passive suspension system has the ability to store energy via a spring and dissipate it via a shock absorber. However, passive suspension system does not have the function of supplying energy to the system. The performance of the passive suspension system can be improved by adding active components to the system.

Semi-active suspension system is modified from passive suspension system by changing the shock absorber to a variable shock absorber [4]. The damping coefficient of the shock absorber can be adjusted in order to follow the road conditions. Active suspension system is a closed-loop control system that consists of external energy source. It is modified by adding force actuator to the system. The performance of the active suspension system can be adjusted due to its closed-loop control system characteristic. Besides that, it has the ability to store, dissipate and to introduce energy to the system. At the moment the sensor of the system detects the changes of the road surface, the data of the road surface will be sent to the controller. Then the controller will calculate amount of energy need to be added or dissipated from the system in order to keep the tire in touch with the road and thus improve the handling quality and ride comfort [2]. Figure 1.3 shows the schematic of passive, semi-active and active suspension system. Schematic of Figure 1.3 is suggested by D.S.Joo et al. [8].

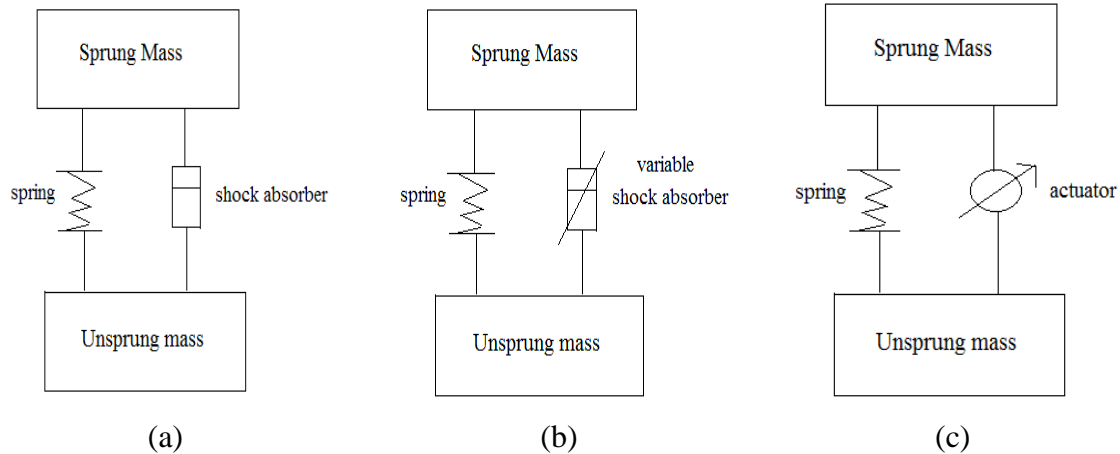


Figure 1.3: (a) Passive suspension system [8], (b) Semi-active suspension system [8], and (c) Active suspension system [8]

1.2 Research Motivation

At present, vehicle suspension system plays an important role in order to guarantee good performance of car. Vehicle suspension system aims to provide passenger with ride comfort while maintaining the safety and stability of the vehicle [3]. However, most of the vehicles are using traditional passive suspension system which has very limited performances and not able to provide good performance of vehicle. When a wheel passes through a bump, there is a vertical force and energy is transferred to the spring which makes it to oscillate vertically. Oscillation of the wheel causes the wheel and the car's frame to move upwards and thus the wheel loses contact with the road surface. Then, the wheel will move downwards back to the ground due to the gravity. When the oscillation of the wheel is large, the suspension travel and the wheel deflection of car are large. Suspension travel is the measured distance between the sprung mass with the unsprung mass. Wheel deflection is the measured distance between unsprung mass with the road profile. Sprung mass are parts of the vehicle supported on the spring such as car body, the frame, the engine, and associated parts. Unsprung mass are parts of vehicle that are not supported by spring, the wheels, tires, and brake assemblies. Figure 1.4 shows the explanation of suspension travel and wheel deflection in picture.

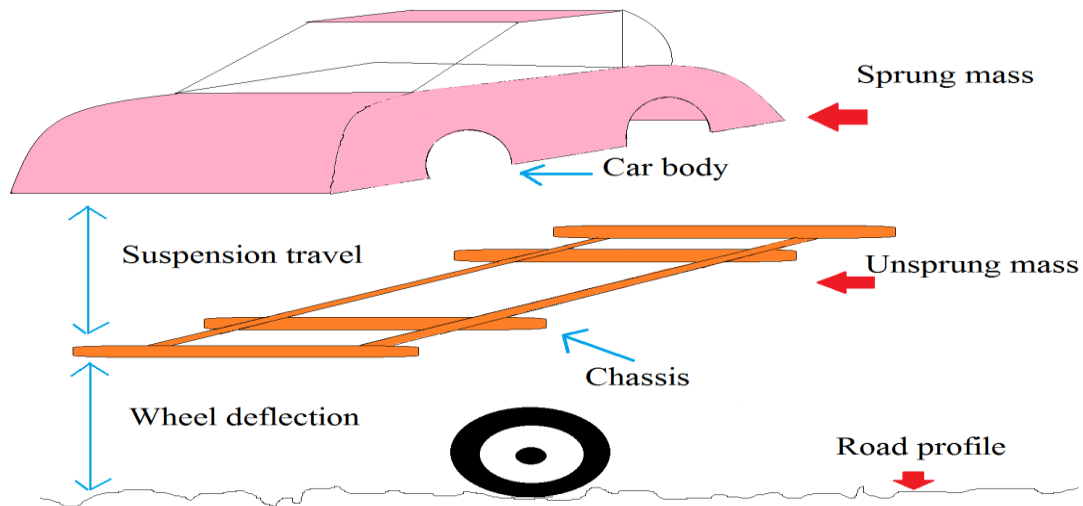


Figure 1.4: Suspension travel and wheel deflection

Therefore, large oscillation between sprung mass and unsprung mass (suspension travel) cause passengers to feel bumpy on the road and bad drive stability. Besides that, passengers will feel the same condition if large oscillation occurs between unsprung mass with road profile (wheel deflection). Passengers feel insecure and not comfortable when sitting inside the car. In long run, bad suspension system could affect the backbone of the passengers and may cause serious injuries.

Thus, analysis on passive suspension system is conducted in order to determine the characteristic of the vehicle suspension system. Proper modeling of vehicle suspension system could lead to good controller design and hence improve the performance of the vehicle suspension system. Vehicle suspension system with controller or active suspension system will be conducted by future final year student. This research will carry out study and analysis on passive suspension system only which represents the open loop system of active suspension system.

1.3 Objectives

- To construct a prototype to represent passive suspension system based on modeling of quarter-car suspension system
- To run open-loop experiments and identify the characteristics of the prototype in terms of the vehicle body and tire positions
- To observe the difference between passive suspension system simulations and experiments in terms of the vehicle body and tire positions

1.4 Scope of Research

This report will primarily focus on the two-degree-of freedom quarter-car model to represent passive suspension system. Semi-active and active suspension system will not be covered in this project. In this report, the simulation and the experiment setup will carry out at the same time. The modeling of the system is simulated by using MATLAB. The performances covered in this project are the vehicle body displacement and tire deflection of vehicle. If the model represents the system well, then the research could be continued on designing a controller. Therefore, vehicle suspension system with controller or active suspension system will be conducted by future final year student.

CHAPTER 2

LITERATURE REVIEW

In previous chapter, a brief introduction about this project has been provided. Now, this chapter will explain more about the vehicle suspension system. Besides that, techniques used to improve vehicle suspension system which have been proposed by other researches will be presented in this chapter.

2.1 Basic Principles

As mentioned in Chapter 1, vehicle suspension system plays an important role in automobile industry in order to guarantee good quality of vehicle. Good suspension system ensures safe ride of passengers and good handling performance by making sure the wheels of vehicle follow the road condition. In addition, suspension system isolates the vehicle body from road shocks and vibration generated by the road surface for comfortable ride [4]. Basically, vehicle suspension system consists of spring, shock absorber and linkages that connect a vehicle to its wheel [16]. There are three types of vehicle suspension system commonly used in the markets which are passive, semi-active, and active suspension system.