MOHD SALEHUDDIN BIN IDRES MH09053 BACHELOR OF MECH. ENG. (AUTOMOTIVE) 2013

ACTIVE FORCE CONTROL ON ACTIVE SUSPENSION SYSTEM

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Report submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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EXAMINERS APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “Active Force Control on Active Suspension System” is written by Mohd Salehuddin Bin Idres. I have examined the final copy of this paper report and in my opinion, it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Engineering.

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award for other degree.

Signature : …………………………………………

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ID Number : MH09053

Date : 25 JUNE 2012

IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL

A special dedication of This Grateful Feeling to My…

Beloved parents, for giving me full of moral and financial support. It is very meaningful to me in order to finish up my degree's study. Do not forget also to my brothers and last but not least to all my lovely lecturers and friends.

Thanks for giving me you Love, Support and Best Wishes.

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ABSTRACT

Active force control system is the most effective and robust system in surpass vibration on suspension system. The objective of this project is to study the performance of AFC on car suspension system. Three type of suspension were tested and compared which is passive suspension, active suspension with PID controller and active suspension with AFC system. The quarter car model is designed. Passive suspension is a suspension system that not equipped with any controller or actuator. For the active suspension, PID controller is used. This controller design deals with selection of proportional gain, derivative gain and integral gain. This parameters (Kp, Kd and Ki) is tuned by using try and error method. For the active suspension with AFC scheme, incorporated with PID controller, it also important to get the optimum value of estimated mass. From the result, active suspension with AFC scheme can reduce more vibration compared to active suspension with PID controller and passive suspension. In conclusion, the AFC system is the most robust and simple system in reducing the vibration on suspension system compared to active suspension with PID controller and passive suspension.

ABSTRAK

Sistem kawalan kuasa aktif adalah sistem yang paling berkesan dan teguh dalam mengatasi getaran pada sistem suspensi. Objektif projek ini adalah untuk mengkaji prestasi AFC pada sistem suspensi kereta. Tiga jenis suspensi telah diuji dan dibandingkan iaitu suspensi pasif, suspensi aktif dengan pengawal PID dan suspensi aktif dengan sistem AFC. Model suku kereta direka. Suspensi pasif adalah system suspensi yang tidak dilengkapi dengan mana-mana pengawal atau penggerak. Bagi suspensi aktif, pengawal PID digunakan. Sistem kawalan ini direka dengan kebolehan untuk menguruskan pemilihan berkadar keuntungan, keuntungan derivatif dan keuntungan penting. Parameter yang digunakan (Kp, Kd dan Ki) ditala dengan menggunakan kaedah cuba jaya. Bagi suspensi aktif dengan skema AFC, selain kawalan PID, ia juga penting untuk mendapatkan nilai berat anggaran. Hasil daripada simulasi, suspensi aktif dengan skema AFC adalah system yang boleh mengurangkan getaran lebih banyak berbanding suspensi aktif dengan kawalan PID dan suspensi pasif. Kesimpulannya, skema AFC adalah sistem yang paling berkesan dan mudah dalam mengurangkan getaran pada sistem suspensi berbanding suspensi aktif dengan kawalan PID dan suspensi pasif.

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LIST OF ABBREVIATIONS

AFC	Active Force Control
FSMC	Fuzzy sliding mode controller
Hz	Hertz
PID	Proportional-Integral-Derivative
PI	Proportional-Integral
PD	Proportional-Derivative

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Car suspension is used to make sure car's wheels are constantly contact to the road and given comfort to the driver and passengers. When a car passing through uneven road profile or hit the bump, it will cause vibration. This unwanted vibration and disturbance force could lead to damaging the structure, causing disturbing noise, fatigue and long term serious injury. This problem of unsmooth road profiles and its effect on vehicle unwanted vibration is due to kinematic excitations. Researchers study about this problem to develop the solution, whose objective is to minimize their effects on the driver and passengers.

Conventional suspension spring and damper characteristics is fixed and cannot be adjust according to specification needs. Standard suspension system only consists of sprung mass, unsprung mass, damper and spring. To minimize the effect of the road profile and maintain driver and passengers comfort follows the road profile circumstance, flexible suspension is being studied theoretically and experimentally by automotive manufacturers and academic research groups. This suspension must be flexible, so that it can be adjust depends on the road profile and desirable performance. Researchers also studied about the new applications of active and semi-active suspension system and special devices to solve this problem.

Semi active suspension is being developed. This suspension system can control the ride height according to the changes in weight and disturbance loading. It can react to internal loading without generating energy to the system. This suspension system also can stop the car from pitching while accelerating or braking.

Active suspension differs from the conventional passive and semi active suspension in which an actuator is attached in parallel with both the spring and the damper to generate energy into the system. The main advantage of employing an active suspension system is, this suspension offers adaptation potential, where the suspension characteristics can be adjust while driving to accommodate the road profile being through. Active suspension being popular topic and researchers comes with many different method and actuator. Yildrim has analysed the differences and made comparison between proportional-integral-derivative controller (PID), proportional–integral controller (PI), and proportional-derivative (PD) controller. While G. Priyandoko, M. Mailah, H. Jamaluddin study on vehicle active suspension system using skyhook adaptive neuro active force control.

Hewitt introduced the active force control concept in late 70s. They design the methodology for using active force control in their study and proposed the actuation concept, alternate control algorithm and also about an approach to solving the problem. In the design process section, they have explored actuators and their technologies, controller hardware and software, and sensors to be integrated effectively into the system. This method is recognized as a simplest, effective and easiest way to control dynamics system. Figure 1.1 shows the diagram of active suspension system including an actuator. The car body represented by the sprung mass, m_s. The tyre, wheels, brakes and part of the suspension is represented by the unsprung mass m_{us}. The suspension stiffness and damping are denoted by k_s and b_s respectively with the tire stiffness denoted by k_t. The road displacement, r, is prescribed by the road profile. Finally, the actuator force is denoted by f_s.

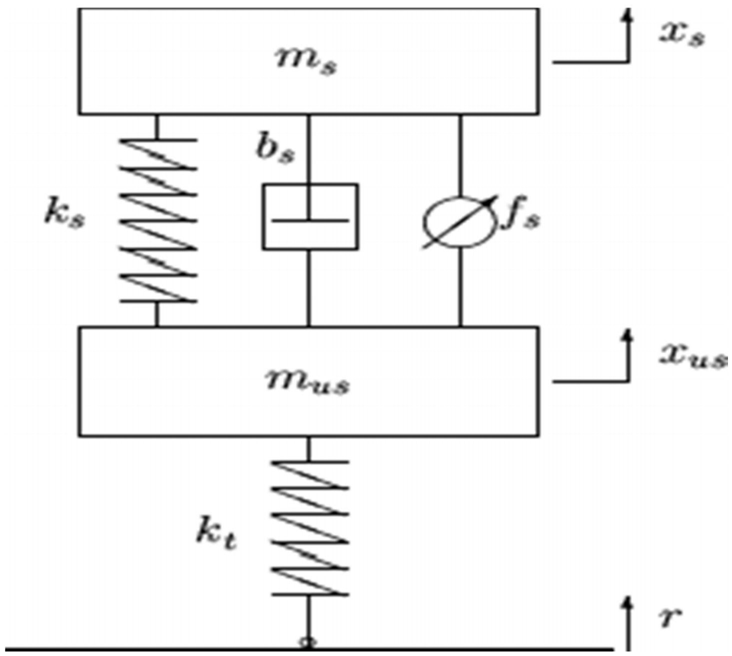

Figure 1.1 : Active Force Control

Where,

m_s = sprung mass

m_{us} = unsprung mass

k_s = spring stiffness

k_t = tyre stiffness

b_s = damping of the spring

f_s = actuator

x_s = sprung mass displacement

x_{us} = unsprung mass displacement

r = road profile

1.2 PROBLEM STATEMENT

Conventional suspension spring and damping characteristics is fixed and it is not adaptive to the varying disturbances which is cause by road profile that being traversed. So, active suspension system is introduced to offers adaptation potential, where the suspension characteristics can be adjusted while driving to accommodate the road profile. This active suspension can be achieved using a few approach such as PID controller, PI controller, PD controller, active force control (AFC) and many more. AFC is known as one of the robust active suspension.

1.3 OBJECTIVE

The objective of this project is to study and do analysing about AFC as force controller on active suspension system. This study will discuss about the effectiveness of using AFC in supressing vibration effect on passenger vehicles. The study will be carried out by using simulation in Matlab Simulink. The result will be analyse and some comparison between different type of suspension system which is passive suspension and proportional-integral-derivative (PID) force control will be made.

1.4 SCOPE

Below is project scope in order to achieve the objective:

1. Analyse and getting further understanding about AFC concept.
2. Study and compare the differences of using passive suspension, PID force control and AFC on suspension system.
3. Make a discussion and conclusion from the simulations in a final report.
4. The study will use the Matlab Simulink environment.
5. One degree of freedom motion are represented by quarter car model.
6. Quarter car model will be used as project model. Sprung mass represent the car body while unsprung mass represent part of suspension, wheel and brakes.
7. Disturbance frequency is 1.5 Hz.

1.5 THESIS ORGANIZATION

Thesis is starts with introduction in chapter 1. It discussed about the background and purpose of the project. Subchapter in chapter 1 is project background, problem statement, objective, and the scope of the project. This project will used simulation in Matlab Simulink environment.

Chapter 2 is literature review. Literature review described the current knowledge related to project about passive suspension system, semi-active suspension system, active suspension system, AFC, and actuator from other researchers.

Chapter 3 is the methodology of the project. It will discussed the plan or method used to do the project and a guidelines in solving the problem. The method used for this project is simulation in Matlab Simulink. Suspension, controller and actuator need to be design while control loop also needs to complete this project.

Next chapter is chapter 4 which is result and discussion. This chapter will show the result from the simulation proses and discuss about it.

Chapter 5 is conclusion and recommendation. It will discuss the conclusion of the project and recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

The purpose of suspension system on vehicles is to improve the ride comfort, road handling and stability of vehicles (Rao, 2010). By introducing of suspension system, acceleration amplitude of the sprung mass of a car may be restricted and tire deflection may be decreased, thereby enhancing effectively the above mentioned features. In 1901 Mors of Paris first fitted an automobile with shock absorbers. With the advantage of a dampened suspension system on his 'Mors Machine', Henri Fournier won the prestigious Paris-to-Berlin race on the 20th of June 1901. In 1920, Leyland used torsion bars in a suspension system. In 1922, independent front suspension was pioneered on the Lancia Lambdaand became more common in mass market cars from 1932. The important consideration is designing suspension is ride comfort, suspension deflection, and tire deflection. Conventional suspension only consist spring and damper without any controlling system.

The problem of this passive suspension is the characteristics of the spring and damper is fixed and cannot be adapt follows the road profile. Semi-active and active suspension is being studied and introduced to offer suspension with adaptive option. Semi-active suspension only capable of energy dissipation while active suspension can either store, dissipate or generate energy for the vehicle. This active suspension spring and damper characteristics can be adjusted while driving accommodates the road profile. It’s also more elastic and efficient than the other types of suspension, making it capable of providing better road-holding ability and ride comfort. Because of it, active suspension system control has attracted the attention of numerous researchers interested in improving the ride and the holding quality of a car.

2.2 QUARTER CAR MODEL

The vehicle model used for this project is quarter car model or one-fourth of the car body mass. This model consist of car body as a sprung mass, tire and brake components as unsprung mass, spring, damper and controller for active suspension system. The assumptions for this quarter car model is there is model is moving in one degree of freedom, tire as a linear spring without damping, spring and damper are moving in linear, wheels is always contact with the road surface, and effect of road friction to the tire is neglected. For this quarter-car model, vehicle roll and pitch motions are ignored and the only degrees of freedom included are the vertical motions of the sprung mass and the unsprung mass (Chantranuwathana, 2004).

2.3 PASSIVE SUSPENSION SYSTEM

Passive suspension is known as earliest and simplest design of suspension. It only consisted of sprung mass, unsprung mass, spring and damper without any force controller as in Figure 2.1. This type of suspension being called passive because it cannot add energy to the system (Rao, 2010). Spring is used to store the kinetic energy produce by the disturbance of the vehicle while damper is used to dissipate this energy. Passive suspension systems are subject to various tradeoffs when they are excited across a large frequency bandwidth. The system is an open loop control system and its designs to achieve certain condition only (Agharkakli, 2012).

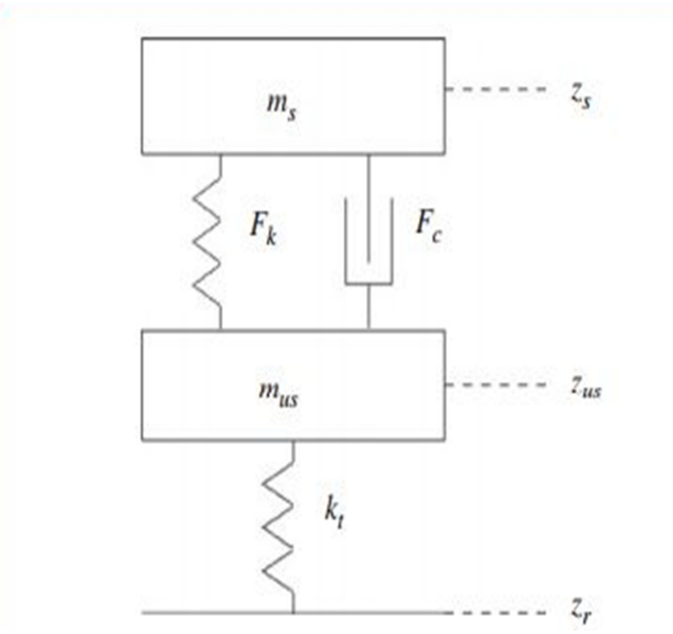

Figure 2.1: Passive suspension system

Source: Poussot-Vassal et al. (2008)

Where :

Fk = Spring stiffness

Fc = Damping constant

Kt = Tyre stiffness

Z_r = Road profile

Z_{us} = Displacement unsprung mass

Z_s = Displacement sprung mass

M_{us} = Unsprung mass

M_s = Sprung mass

Equation of motion for this passive suspension is :

Equation 1 : MsZs + Fk (Zs - Zus) + Fc (Zs - Zus) = 0 (2.1)

Equation 2 : MusZus - Fk (Zs - Zus) - Fc (Zs - Zus) + Kt (Zu – Zr) = 0 (2.2)

Passive suspension spring and damper characteristics is fixed and cannot be adjust according to specification needs.

2.4 SEMI-ACTIVE SUSPENSION

Semi-active suspension becomes popular research topic by automotive and academic researchers in order to improve the conventional suspension. This suspension offer improvement in ride quality by minimizing sprung mass acceleration and displacement. Semi-active suspension systems offer the adaptation of the damping or the stiffness of the spring to the actual desired response (Rao, 2010). It can control the vehicle height according to the changes in weight and disturbance loading. This system reacted to the internal loading without generating energy to the system. Typical bandwidth for semi-active suspension is 0-5 Hz.

Numerous type of semi-active suspension have been proposed and introduced such as using actuator magnetorheological (MR) fluid dampers, skyhook control, relative control and many more. Compare to active suspension, the disadvantage this type of suspension is it only can dissipate kinetic energy from disturbance without generate energy to the system. So it only effective on small frequency disturbance and low speed vibration.

2.5 ACTIVE SUSPENSION SYSTEM

Active suspension is a suspension with high bandwidth (0-50 Hz) which the springs and dampers of passive suspension are replaced by hydraulic struts controlled by a fast-acting closed loop control system. Theoretically, this suspension allows reduction in body vertical acceleration and can provide a driver and passengers less isolation from road unevenness while keeping admissible the road holding performances. The idea is that when the car meets a bump, the appropriate strut will retract the wheel. Conversely, when the car meets a hole, the strut will force the wheel downward. Both cases maintain the vehicle body at a constant ride height for driver and passengers comfort.

Various type of active suspension being study and develop by academic researchers and automotive engineers. Many technical papers were written about it or related subjects. However they are facing many problems from this development such as high cost of the system, high power consumption, low bandwidth, and limited usability. This suspension consists of various types of actuator such as PID controller, PI controller, AFC and many more.

Citroen Automotive were the first automotive group seriously introduced and applying active suspension on their automobile. This active suspension is developed based on a hydro pneumatic suspension. Lotus teams then developed this system and introduced it to their Formula 1 Grand Prix car between 1977 and 1982 (Ikenaga, 2000). They found it quite effective in improving their handling ability.

Fuzzy sliding mode controller (FSMC) is used to control an active suspension system and evaluated its control performance (Jeen Lin, 2009). FSMC will detect the error change to establish a sliding surface, and then introduced the sliding surface and the change of the sliding surface as input variables of a traditional fuzzy controller (TFC) in controlling the suspension system. He used quarter car model in Figure 2.2 as suspension model.

Figure 2.2: Quarter car model

Source: Jeen Lin (2009)

2.5.1 Active Suspension System with PID Controller

Proportional Integral Derivative (PID) controller is generic control loop feedback mechanism. This type of controller is widely used in industrial control system. This controller is function to correct the error between measured process variable and give a corrective action that can adjust the process (Salim et al, 2011). Example of usage PID controller is on active vehicle suspension. This system well known as excellently used for little disturbance and low speed vibration. However, PID controller performance is decreased when the system is operating at high speed and with presence of high disturbance (Mansor et al, 2010).

The process of selecting the controller parameters to achieved given performance specification is known as controller tuning (Mouleeswaran, 2012). The parameters need to be tuned is Kp, Ki and Kd. This controller needs to be tuning until we get the desired responses. In many case, series of fine tunings are needs until an acceptable results is obtained. Figure 2.3 shows the PID controller plant.

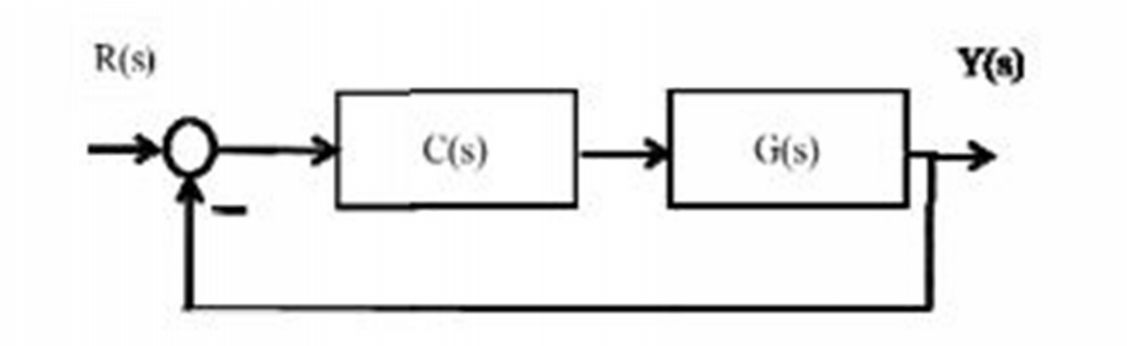

Figure 2.3: PID controller plant

Source: Salim et al (2011)

The PID system is designed prior to the implementation of AFC. The transfer function of a PID controller is given below :

$$G(s) = K_P(1 + \frac{1}{K_I s} + K_D s) \tag{2.3}$$

Where:
Kp = Proportional gain
Ki = Integral gain
Kd = Derivative gain.

2.5.2 Active Suspension System with Active Force Control

Works on Active Force Control (AFC) have been started by Hewit and co-workers in the early eighties which demonstrate that the dynamic systems under study can be made robust and stable in the presence of disturbances, uncertainties and/or parametric changes, provided that a number of simple criteria are fulfilled (Priyadonko, 2008). They design the methodology for using active force control in their study and proposed the actuation concept, alternate control algorithm and also about an approach to solving the problem. AFC can be shown in simple Newton's second law of motion:

$$F + Q = ma \tag{2.4}$$

Where F represented the applied force, Q is the disturbance, m is a mass of spring mass and a is the value of the spring mass acceleration. In the design process section, they have explored actuators and their technologies, controller hardware and software, and sensors to be integrated effectively into the system. This AFC is well known as a simplest, robust and most effective controlling system compared to others. Figure 2.4 shows the model of AFC system. The r, K_t, K_s, b_s, f_s, X_s, X_{us}, m_s and m_{us} represented road profile, tire stiffness, spring stiffness, spring damping, actuator force, sprung mass displacement, unsprung mass displacement, sprung mass and unsprung mass respectively.

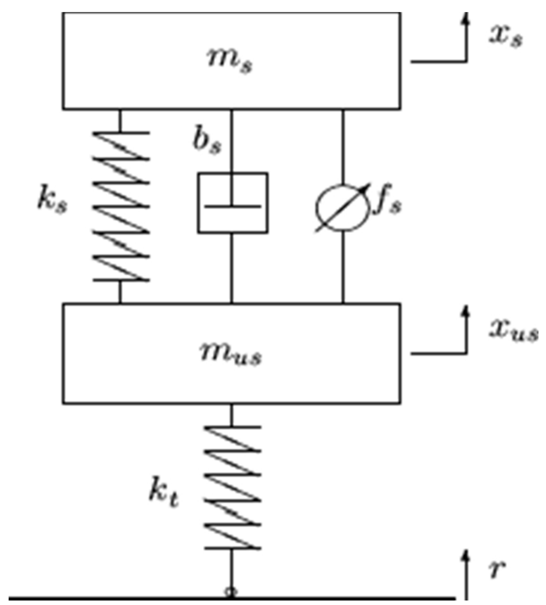

Figure 2.4: Active force control

Priyadonko in his study shows that the amplitudes of the sprung mass acceleration, and displacement for an active suspension based on skyhook adaptive neuro active force control (SANAFC) have a better performance compared to both the PID controller and the passive suspension system (Priyadonko, 2008). The AFC scheme for active suspension used by Priyadonko is in Figure 2.5. From his study, the inverse dynamics of the actuator are determined using neural network (NN).

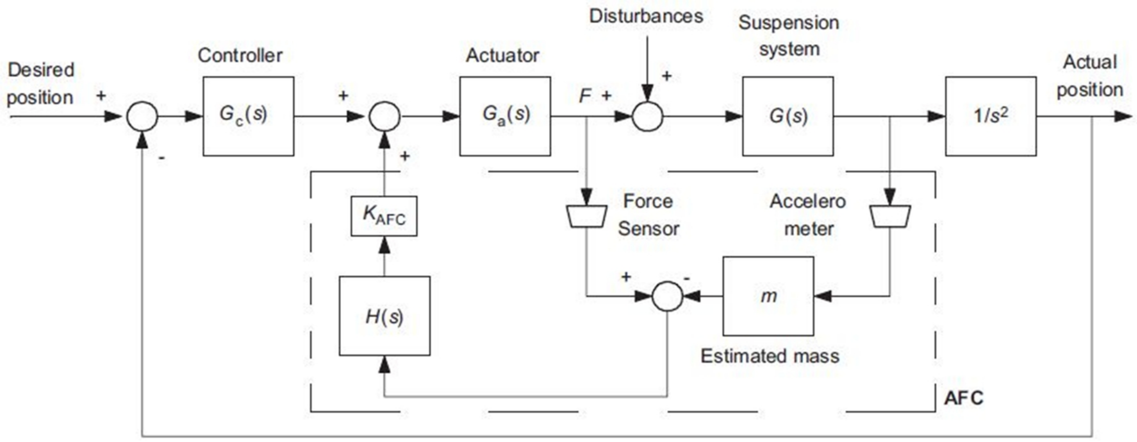

Figure 2.5 : AFC scheme for active suspension

Source : Priyadonko (2008)

2.6 MAGNETIC ACTUATOR

Magnetic actuator is an actuator which can deliver high-output forces, be driven at high frequencies and used very broad in various fields. In automotive, it used as force controller for active suspension. Magnetic actuator being developed to maximize suspension efficiency and increase its bandwidth. Magnetic actuators can be rotary or linear, and can have continuous or limited motion. The basic classes being are moving-coil, moving-iron and moving-magnet. Within these, the air gap length may either remain constant or vary with displacement, and while the majority of such actuators have only one degree-of-freedom, systems are emerging which are capable of providing multiple degrees-of-freedom of controlled motion. This actuator is force-controlled, using inner force-feedback loops and carefully designed to achieve the required performance.

Novel tubular permanent magnet electromagnetic actuator was designed as in figure 2.6. This actuator is able to transfer direct drive in a small volume and can achieve higher bandwidth compare to other active systems. The electro-magnetic actuator is connected in parallel with a mechanical spring to maintain the height of the vehicle.

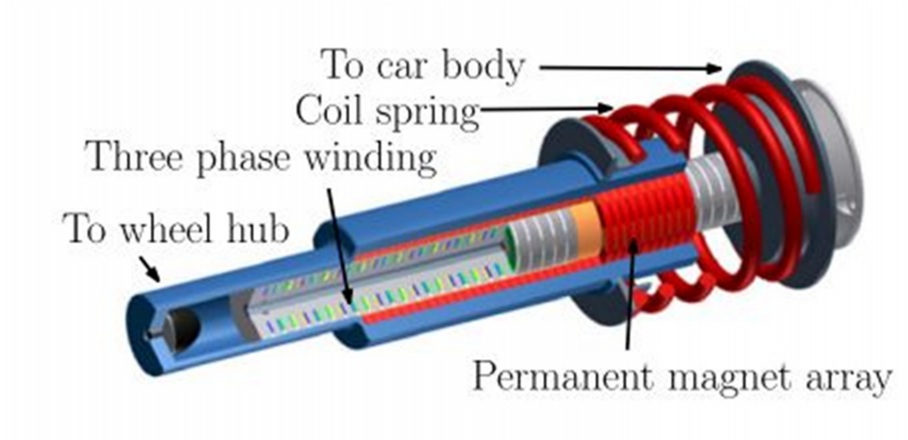

Figure 2.6 : Turbular permanent magnet electromagnetic actuator

Source : Sande et al. (2012)

Magnetic actuator can greatly improve vehicles comfort and stability up to 41% of improvement (Sande et al, 2012). This improvement is achieved by minimized the sprung mass acceleration and displacement on given road disturbance.

The elect of air gap variations makes an electro-magnetic actuator on its own an unstable system, although fitting this in parallel with the auxiliary mass's own suspension will tend to overcome the stability. However a properly designed force feedback loops overcomes any residual instability, but it is important to model the characteristics properly to choose appropriate values for the PI controller and to give correct predictions of performance (Foo & Goodall, 2000). Electromagnetic actuator is small enough to be fitted on car suspension system. Also the high-bandwidth capability of such actuators makes them very appropriate for controlling the vibration in flexible modes. The model to represent the dynamics of the central electromagnetic actuator is in Figure 2.7 while Figure 2.8 show magnetic actuator control loop.

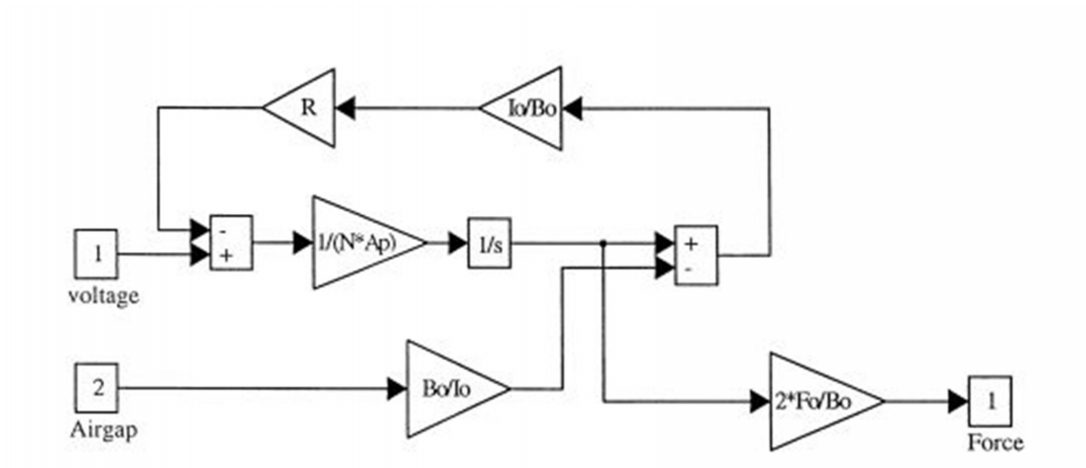

Figure 2.7 : Model of electro-magnetic actuator

Source : Foo & Goodall (2000)

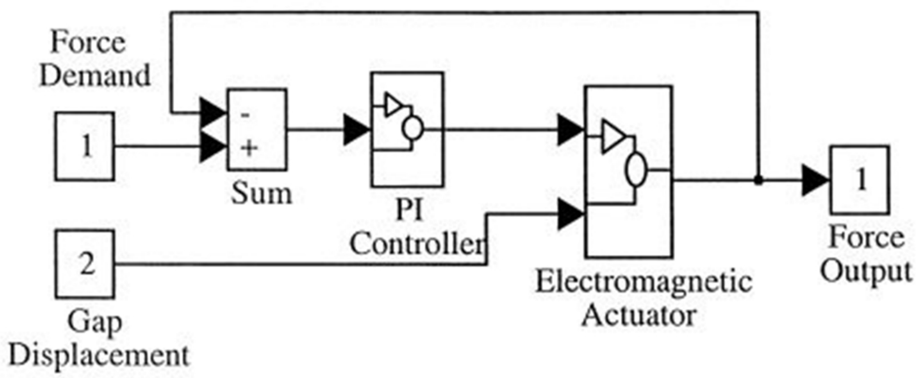

Figure 2.8 : Electro-magnetic actuator control loop

Source : Foo & Goodall (2000)

2.7 SUMMARY

Suspension system is introduced on vehicles to improve the ride comfort, road handling and stability of vehicles. This purpose is being achieved by minimized the displacement and acceleration of the sprung mass. Passive suspension is conventional suspension system where the characteristic of the spring and damper is fixed and cannot be adjust according to the desired response. To improve the suspension system and driving comfort, semi-active and active suspension system is introduced. This type of system can offer the adaptation of the damping or the stiffness of the spring to the actual desired response. By applying this system on suspension system, we can greatly improve suspension system and riding comfort of the vehicle. Active suspension with AFC scheme has been started by Hewitt and co-workers in eighties. They design the methodology for using active force control in their study and proposed the actuation concept, alternate control algorithm and also about an approach to solving the problem. This system is well-known as most robust and simplest system for active suspension.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains clearly the step taken to complete the simulation in obtain the result and discussion. The procedure must be done systematically to make sure there is no mistake and conflict on the result obtain. A good methodology can describe the project flow smoothly and the project framework that contains the process element hence it becomes the guideline to find the objective required.

The work presented here is to analyse the effect of using passive suspension, active suspension with PID controller and active suspension with AFC system on car suspension of a quarter car model for a given road profile. The analysis is using state space equations in Matlab and equation of motion using mathematical blocks available in Simulink. The quarter car model will be used for simulations model and the road description.

3.2 FLOW CHART OF METHODOLOGY

The planning is very important to give an illustration about the project flow process to make sure the progress project is satisfied with the time required. Hence the project will run smoothly as scheduled.

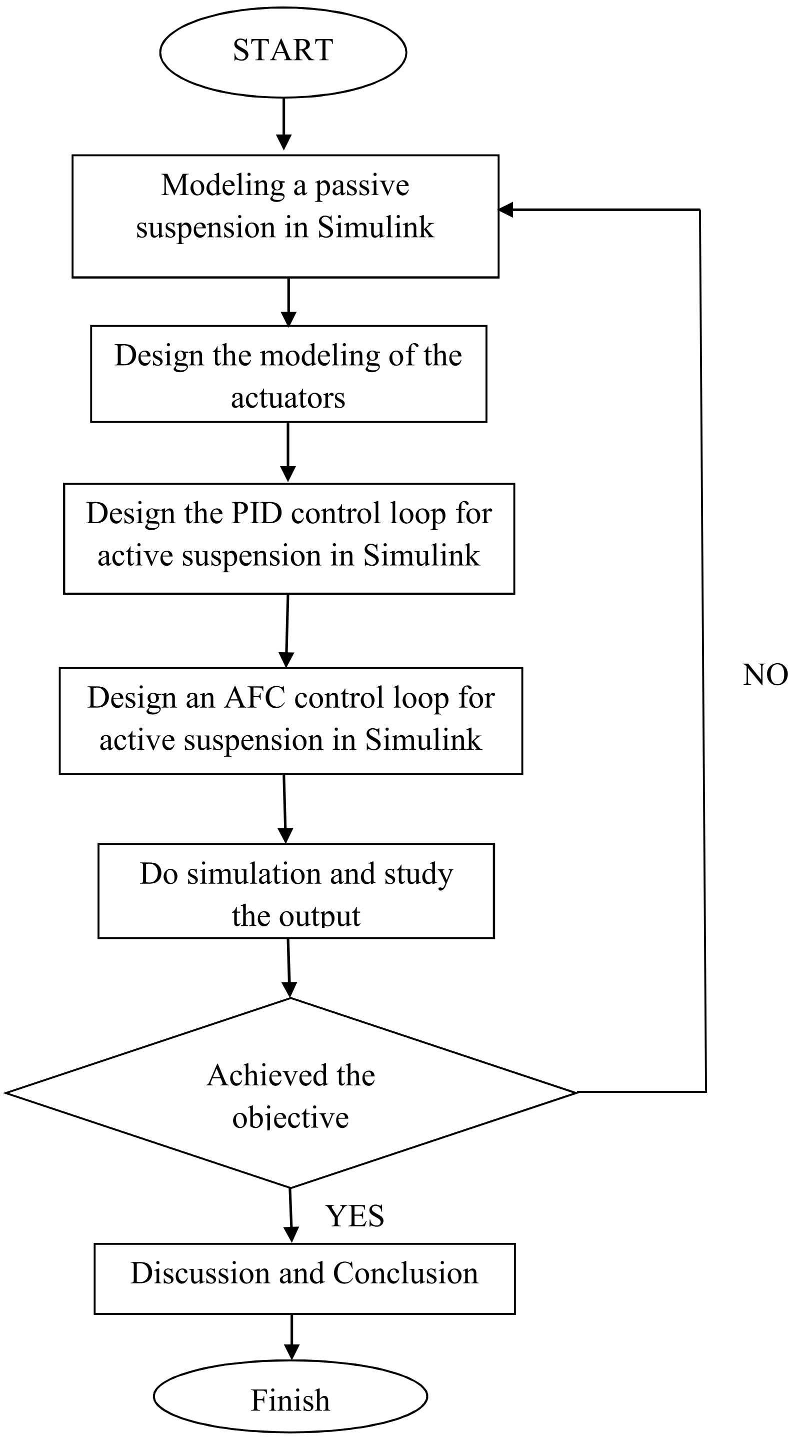

Figure 3.1: Flow Chart of Methodology

According to the flowchart above, the project starts with discussion with supervisor about the title, objective and scope of the project. After that is a literature review, consist of the review of the title and scope of the suspension system. These tasks have been done through finding a related journal, thesis, and other sources from the internet.

After gathering all the relevant information, the project undergoes design process. In this part, project begun with develop the passive suspension model and control loop for the Matlab Simulink. Based on related journal and source from internet, the control loop and model of passive suspension has been obtained. By using the parameters taken from the other journal, the simulation process started.

The project continues with developing the active suspension model with PID controller and AFC for the simulation. After the control loop has been obtained, this controller need to be tuned. The parameters for the suspension also need to be decided. This system is being tuned by using try and error method until get the best possible result. For the AFC, beside of tuning the PID controller, estimated mass also important to get the best result.

For the simulation process, 4 types of road disturbance have been used to make sure the result is match to each other. The input is used is step input of 0.03, sinusoidal input with frequency of 1.5 Hz and 4 Hz, repeating sequence input with time value [0, 2], output value [0, 2] and pulse generator with amplitude of 0.1m, period of 2 seconds. This input is used for every suspension system, passive suspension, active suspension with PID controller and active suspension with AFC.

After done with the simulation, next task is to do analysis and comparison for every output. The analysis is done by comparing the sprung mass displacement between three system used and for every input. All data such as time response, amplitude, and error are collected.

After that, slide presentation is being prepared for the final presentation. This slide contains of the information about the project, methodology and result of the project to be present to the panel.

For the final part is to complete the thesis to be submitted to the university and further action.

3.3 DYNAMIC MODEL

Dynamic model used for this project is quarter car model. This model consists of one fourth of the sprung mass, suspension components system and unsprung mass. Figure 3.2 show the dynamic model of quarter car model. Quarter-car model is widely used for suspension analysis because this model is simple and can represent the important characteristics of full model.

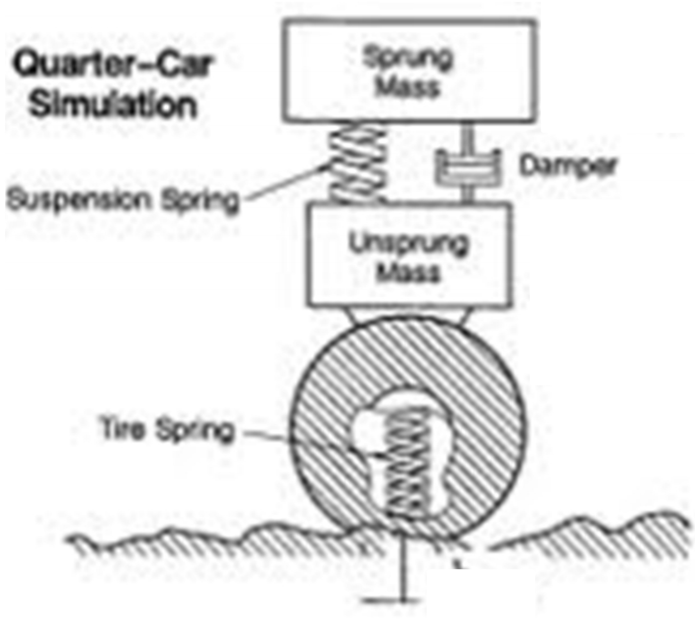

Figure 3.2: Quarter car model

3.3.1 Designing Suspension Model

The test setup consists of a full-size quarter car model as project model. The sprung mass (m_1) represented the car body and unsprung mass (m_2) as a part of suspension, wheel and brake represented by blocks as Figure 3.3 shows. These two masses are connected by a suspension (k_1) and damper (b_1). Tire stiffness is represented by k_2 while road profile is w.

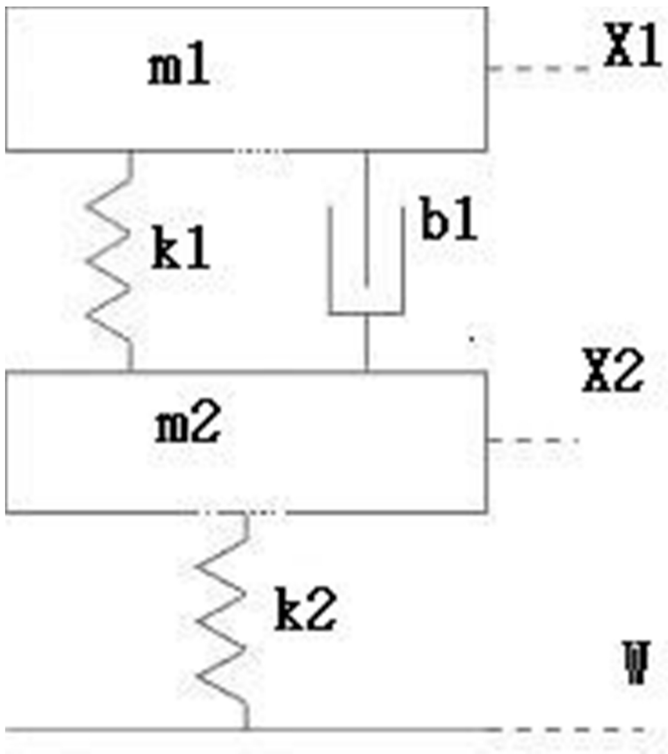

Figure 3.3: Vehicle suspension model

Equation of motion for passive suspension is :

Equation 1: $m_1x_1 + k_1 (x_1 - x_2) + b_1 (x_1 - x_2) = 0$ (3.1)

Equation 2: $m_2x_2 - k_1 (x_1 - x_2) - b_1 (x_1 - x_2) + k_2 (x_2 - w) = 0$ (3.2)

3.4 BLOCK DIAGRAM

Blog diagram show how the component related to each other in simple way. Every block or shape represents components, parts or function of the system. This component is depends on each other and show what the input, output and the process for the system.

Figure 3.4 show the open loop blog diagram. For suspension system, this blog represent the passive suspension with no feedback or self-correcting. Figure 3.5 show the closed loop blog diagram where this diagram also can represented an active suspension system. This system has a feedback and self-correcting in order to improve the system.

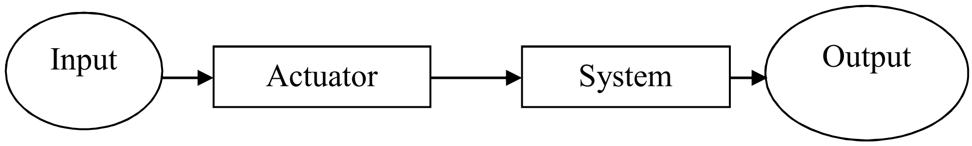

Figure 3.4: Open Loop System

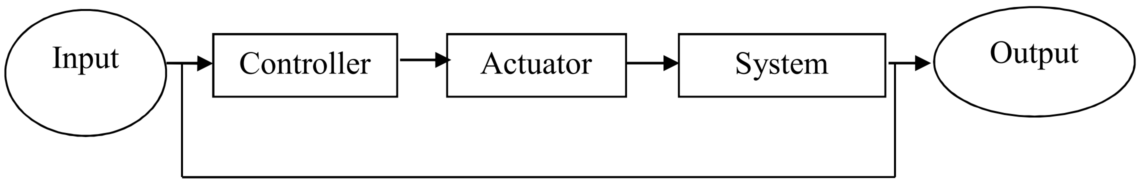

Figure 3.5: Closed Loop System

3.5 PARAMETERS

For the simulation purpose, the values of sprung mass, unsprung mass, damping constant and spring constant are considered properly. Table 3.1 shows the assumed values of that parameters. This parameters are taken from previous researches.

Table 3.1: The parameter used for the simulation

Parameters	Value
Body mass (m_1)	240 kg
Suspension mass (m_2)	25 kg
Spring constant of suspension (k_1)	16,000 N/m
Spring constant of wheel and tire (k_2)	190,000 N/m
Damping constant of suspension system (b_1)	1000 Ns/m
Disturbance(w)	1.5 Hz

Source: Priyadonko (2008)

3.6 SIMULATION

In this research, simulation process is used to investigate the performance of suspension system of quarter car model. The computer software used for the simulation is Matlab. The Simulink model for quarter car model was developed before the simulation process started. 3 type of model has been developed which is passive suspension model, active suspension with PID controller and active suspension with AFC system. Various type of disturbances used for the simulation to evaluate the robustness of the system. Those disturbances are step, repeating sequence, sine wave and pulse generator. The performance of suspension system is evaluated through vibration of sprung mass in displacement. The sprung mass displacement graph response being analyze and used for result discussion.

3.6.1 Passive suspension

Generally, passive suspension is a suspension system that not equipped with any controller to the system. The control loop of passive suspension structure in Matlab

Simulink as shown in Figure 3.6 is used. This control loop is produced by expanding the equation of passive suspension and transferring the parameters used to the Simulink scheme. To gain the result of the simulation, the step input with height 3cm at t=0 sec were transferred to the software. By consider the road condition with the bump of 3 cm. The desire output used for this simulation is 5 cm.

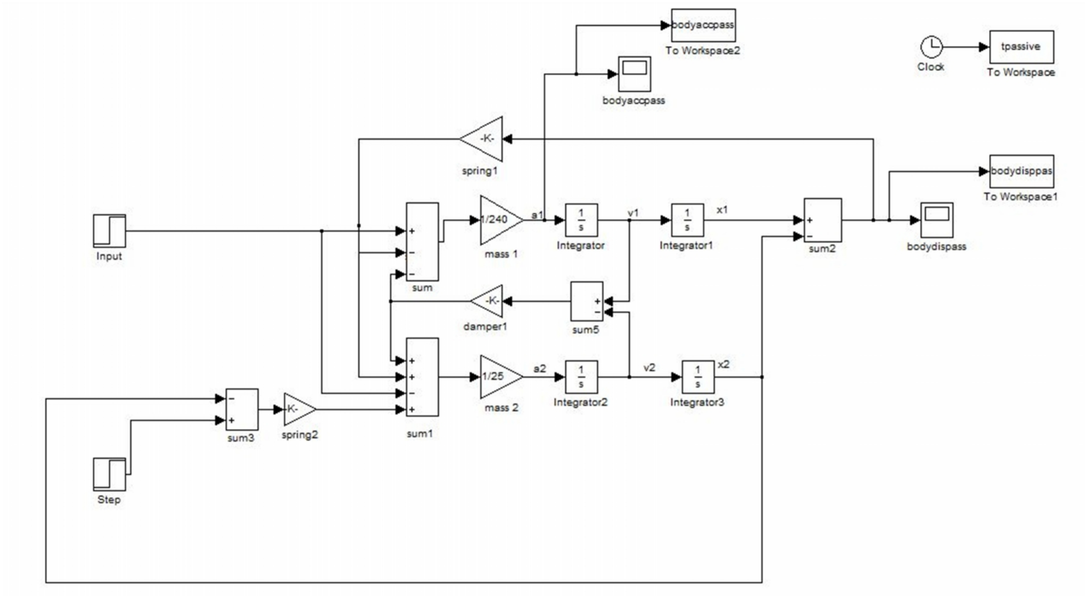

Figure 3.6: Control loop for passive suspension

3.6.2 Active Suspension

This section will discuss about the simulation of the active suspension system. Two types of active suspension has been used which is an active suspension with PID controller and active suspension with AFC system.

3.6.2.1 Active suspension with PID controller

A proportional-integral-derivative controller (PID) is a common use feedback look component in control system industry. The difference or error is then used to adjust some input to the process in order to bring the process measured back to its desired value. This controller can be easily being adjusted from the Simulink's block application. K_p as proportional gain, K_i as integral gain and K_d as the derivative gain. The active suspension system with PID controller structure has been built as in figure 3.7. Then, its being tuned by using Ziegler-Nichols tuning rules, the value of P,I and D is determined. This method started by reducing the integrator and derivative gains to 0 (KI and KD equal to 0). Then increase KP from 0 to some critical value Kp = Kcr at which sustained oscillations occur. After get the value of Kp, increase the value of Ki and Kd until get the desired response. This value is being adjusted until get the best graph response.

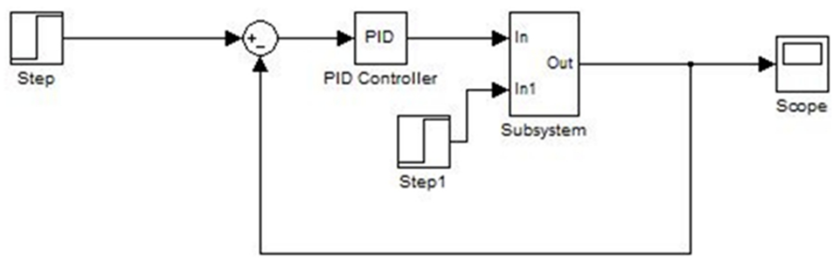

Figure 3.7: Control loop for active suspension with PID controller

3.6.2.2 Active Suspension with AFC system.

Active Force Control (AFC) known as a most robust and effective control system in minimizing the vibration. The AFC principle is to use some measured and estimated values of the identified parameters, the actuated force, displacement of the body and its estimated mass, and then incorporate them into the controller to activate the disturbance rejection capability. In practice, the estimated mass of the system should be appropriately estimated using suitable methods. For this project, AFC control loop as in figure 3.8 is used for the simulation. The actuator value is randomly chosen. This value can be any suitable value. The estimated mass being appropriately approximates until get the best response to surpass the vibration. In this study, a crude approximation method was used and the parameter was given a constant fixed value.

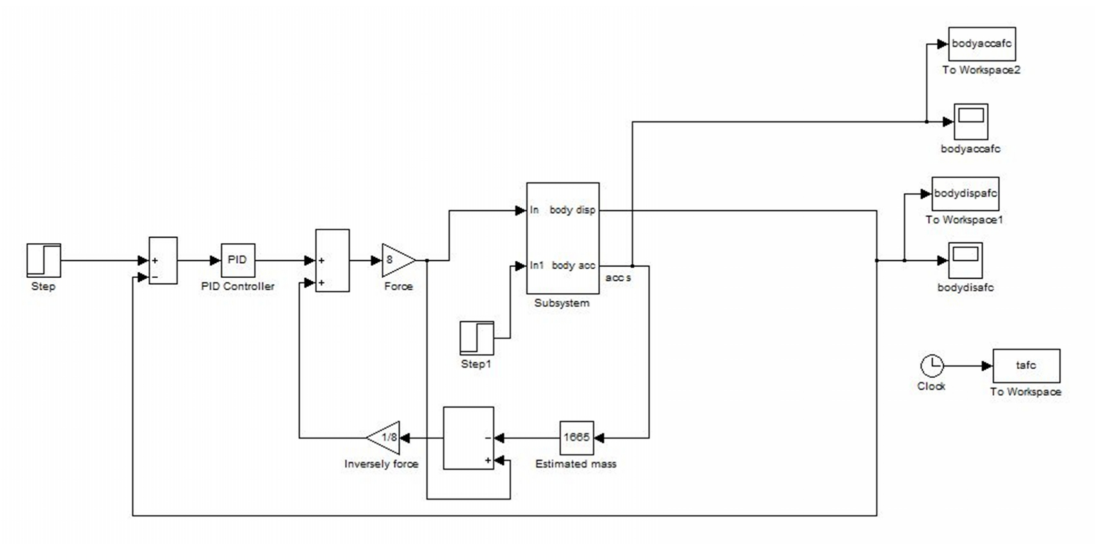

Figure 3.8: Control loop for active suspension with AFC system

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The methodology in the previous chapter already explained the step in analysing the suspension system using Matlab Simulink. This chapter will discuss the result form graph obtained. The result will be show clearly starting from the first step which is analysis for passive suspension system without, active suspension with PID controller and active suspension with AFC scheme. The results will be present in form of diagram and graph structure. All the result obtained will be compare in discussion part. The comparison will be done by analyse the effect of different disturbance source to displacement of the sprung mass.

4.2 RESULTS

The simulation was done by input of step, repeating sequence, sine wave and pulse generator. This various type of input was used to analyse the robustness of the system.

4.2.1 Analysis of Passive Suspension versus Active Suspension System with Step Input

The first input used is step with final value of 0.03m and t=0s. This value represent as a bump road with height of 3cm. Figure 4.1 below shows the result of suspension dynamic system that had been run using Matlab Simulink. Time used for this simulation is 10 seconds and the desired output is 0.05m. Figure 4.1 is a graph displacement of sprung mass versus time for passive suspension with step input. This system can’t achieve the desired output which is 0.05m and the settling time for the suspension to back to normal position is 4.179 seconds.

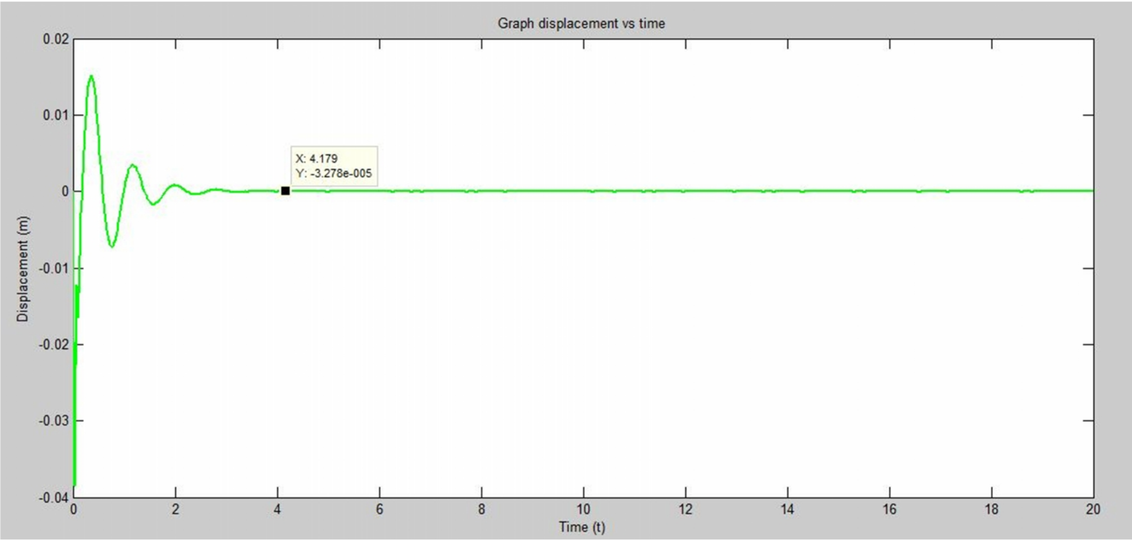

Figure 4.1: Graph displacement versus time for passive suspension

Next figures show the simulation result of the active suspension with PID controller. To get the best result for this system, the proportional gain (P), integral gain (I) and derivative gain (D) values need to be tuned properly. Figure 4.2 show the response of PID controller on first trial. The value for first trial is 10000 for P, 1000 for I and 10000 for D. This tuning not achieved the desired value which is 0.05. This result also has a overshoot.

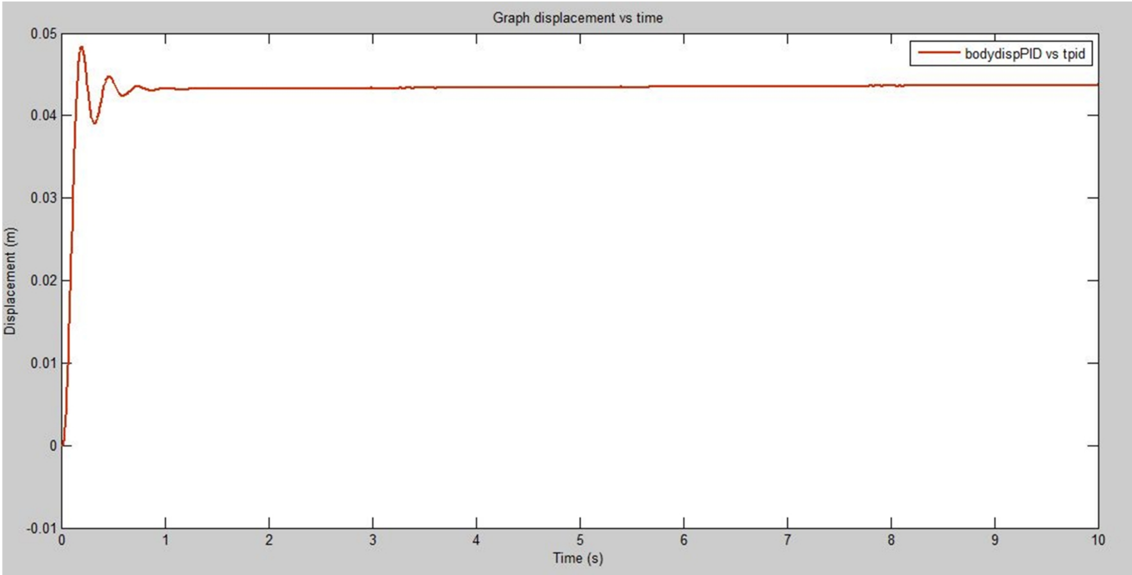

Figure 4.2: Graph displacement versus time for active suspension with PID controller first trial.

Proportional, Kp	: 10000
Integral, Ki	: 1000
Derivative, Kd	: 10000

After many trials by using try and error method, the best value for each parameter is 10500 for P, 45000 for I and 28000 for D value. As shown in figure 4.3, the desired value of 0.05 was achieved with settling time of 5.641 seconds and zero overshoot. . This new PID value will be used as PID for the comparison with passive system and active suspension with AFC system.

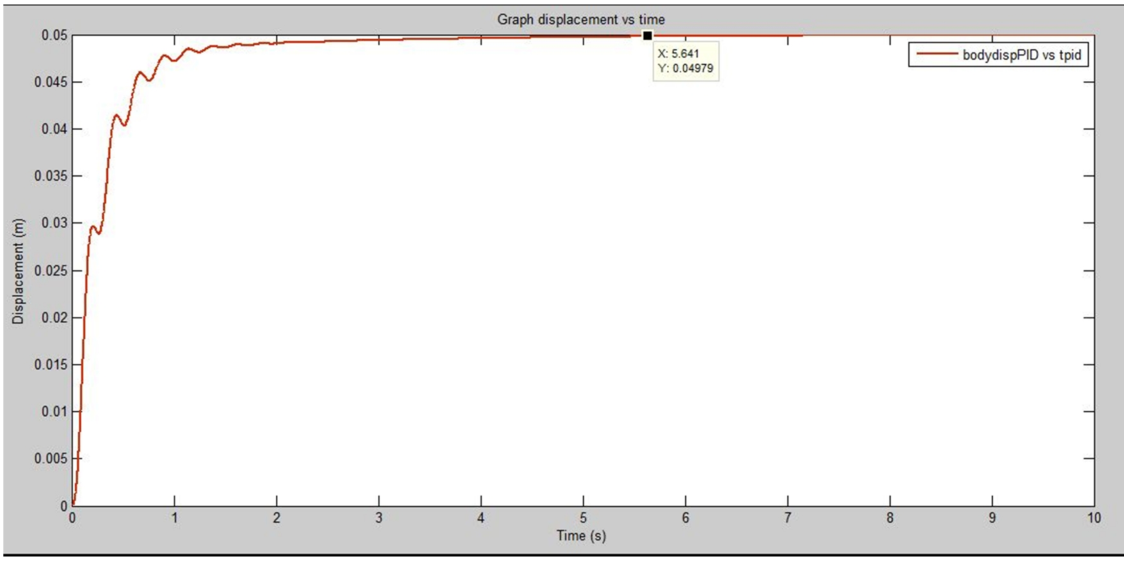

Figure 4.3: Graph displacement versus time for active suspension with PID controller after tuning

Proportional, Kp	: 105000
Integral, Ki	: 45000
Derivative, Kd	: 28000

Next figure 4.4 is the graph of displacement versus time for active suspension with AFC system. By properly tuned the PID controller and estimate the estimated mass, this system get the best response. Crude approximation technique was used to estimate the estimated mass (*M**) and it is a constant value. After many trials, the optimum estimated mass found for this system is 1000. This system achieved the desired value at t=3.093 seconds and without overshoot.

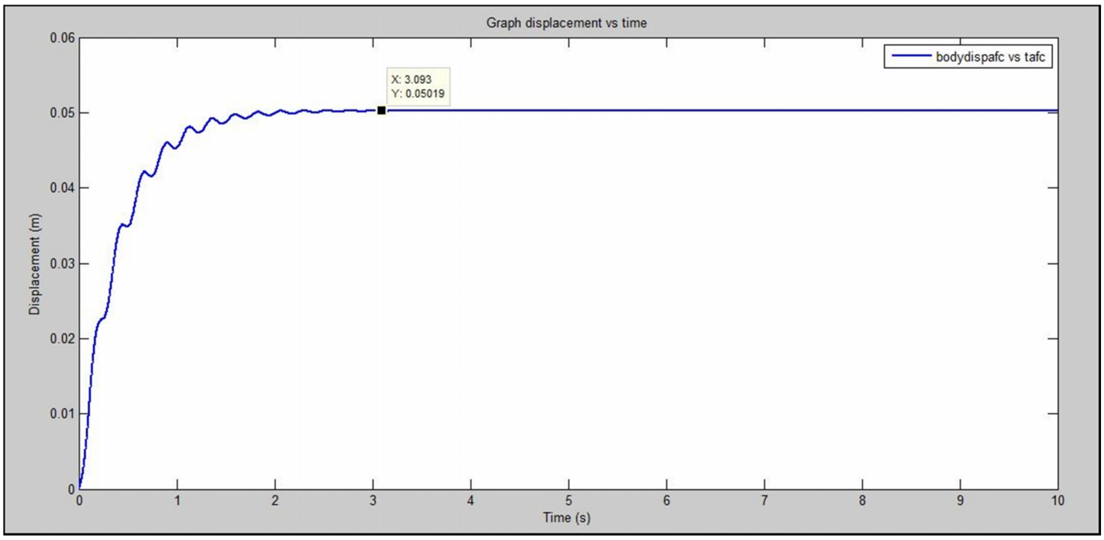

Figure 4.4: Graph displacement versus time for active suspension with AFC system

The comparison graph of displacement versus time for passive suspension and active suspension shown in figure 4.5. From this graph, we can see that active suspension can achieve the desired output compared to passive suspension. It shows that active suspensions with controller are capable of tracking the desired output. This signifies that the appropriate controller setting enables the active suspension system to work properly. Both active suspension systems achieved the desired value without overshoot. Active suspension with the AFC system have a shorter rise and settling time which is 3.093 seconds compared to PID controller which is 5.641 seconds.

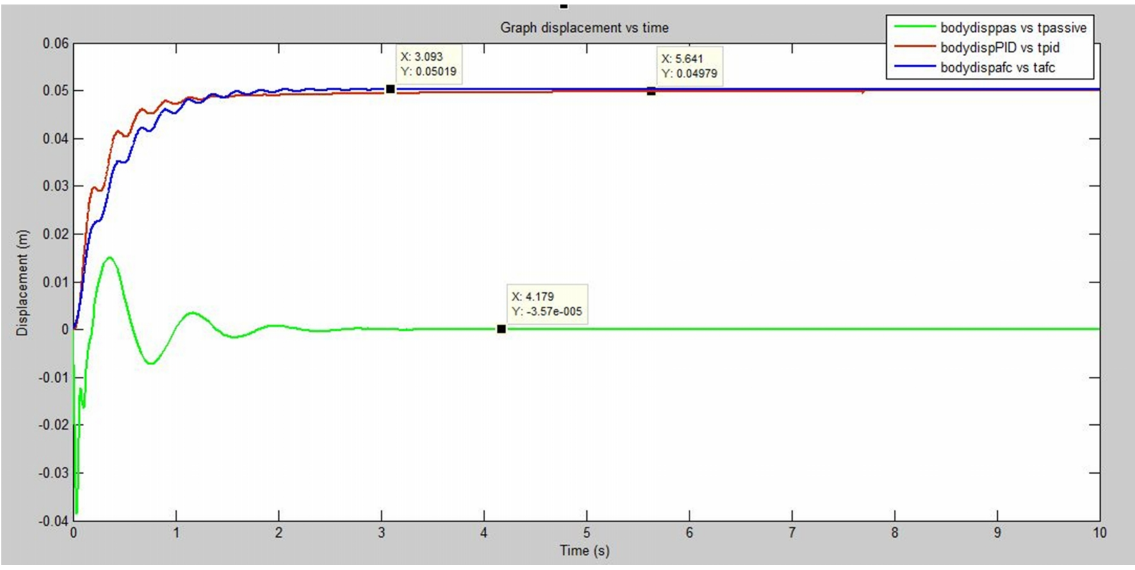

Figure 4.5: Graph displacement versus time for passive suspension and active suspension

4.2.2 Analysis of Passive Suspension versus Active Suspension System with Sinusoidal Input.

Next road profiles used is sinusoidal signal amplitudes of 0.1 and frequency of 1.5 Hz. The frequency of 1.5 Hz is chosen, because it's close to the frequency of the body of the suspension system which is approximately 1 Hz. The performance of the suspension system being analysed by considering the ability of the system to suppress or reduce the effects of the introduced disturbances. The behaviour of the active suspension system with a sinusoidal road inputs shows significant reduction in sprung mass displacement. As shown in figure 4.6, the reduction of sprung mass displacement is up to 200%. This result proved that active suspension with AFC system (blue line) is the best system in suppress the vibration and improve suspension system compare to active suspension with PID controller and passive suspension.

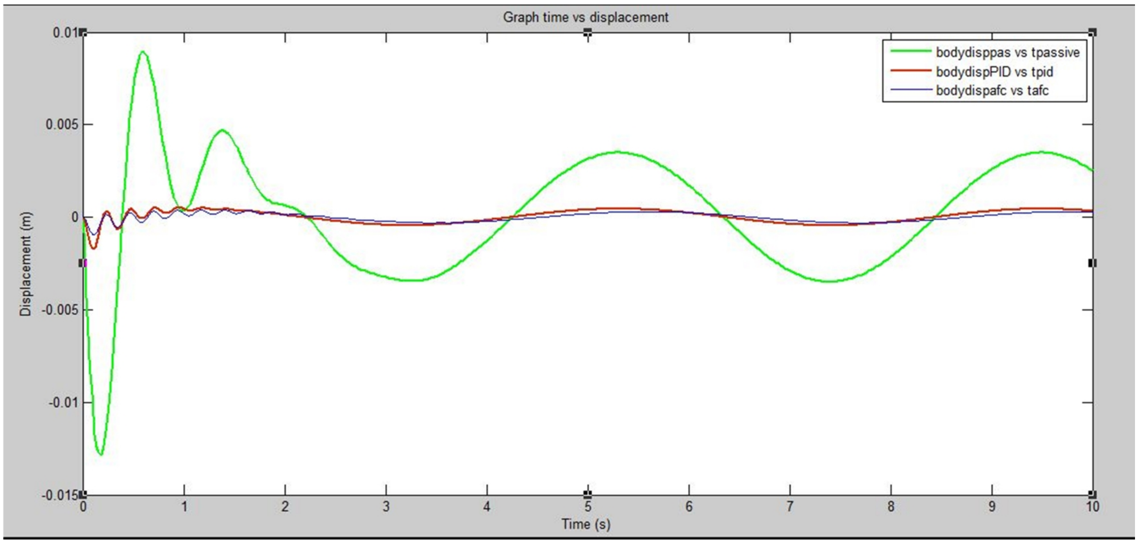

Figure 4.6: Graph displacement versus time for passive suspension and active suspension with sinusoidal input 1.5 Hz

Next figure 4.7 show the response output of the suspension system with input of sinusoidal input of 4 Hz. From this graph we can see that blue line (Active suspension with AFC system) has the smallest amplitude compared to red line (Active suspension with PID controller) and yellow line (Passive suspension). By increasing the frequency, we can see that the response amplitude also increase but the time for one complete oscillation become shorter.

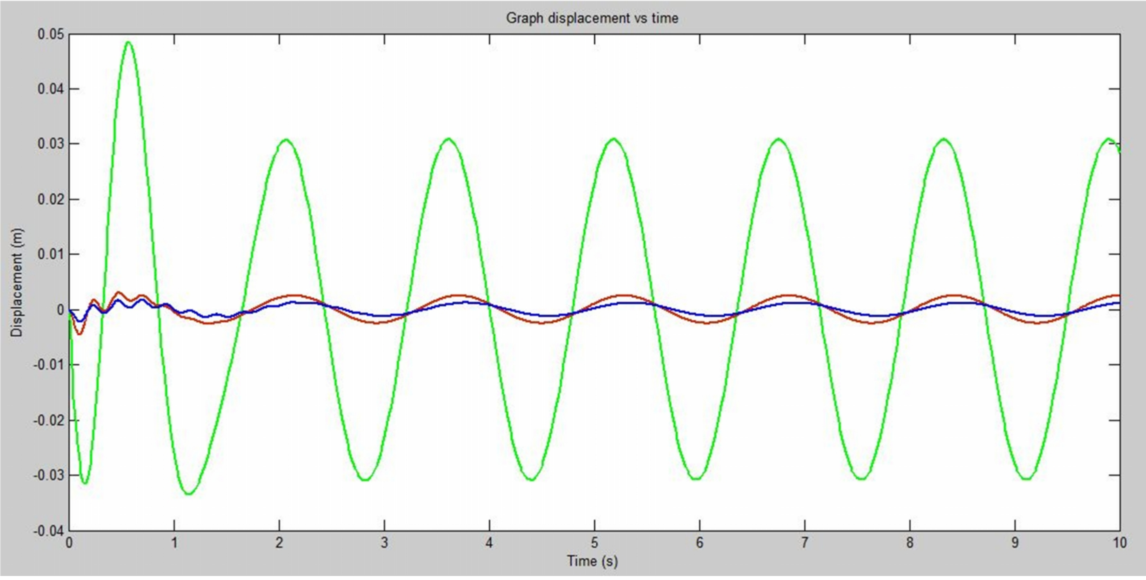

Figure 4.7: Graph displacement versus time for passive suspension and active suspension with sinusoidal input 4 Hz

The value of sprung mass displacement is smaller for the lower frequency 1.5 compare to 4 Hz. From the oscillation, the rate of suspension displacement is lower and time period for one complete oscillation become longer. This provide comfortable car riding for active suspension system because the suspension system absorb the vibration more effectively compared to passive suspension which is seem too soft. The lower frequency gives a better performance results compared to higher frequency.

4.2.3 Analysis of Passive Suspension versus Active Suspension System with Repeating Sequence Input.

Next input used is repeating sequence with time value of [0, 2] and output value of [0, 2]. Figure 4.8 below show the graph of displacement versus time for this simulation. From the graph, we can see that passive suspension with green line have a higher amplitude response compared to active suspension. Active suspension with PID controller and AFC scheme has lower amplitude by considering peak to peak value of the graph compared to passive suspension. There is significant reduction of the displacement of sprung mass thereby improving the suspension performance. The lowest amplitude is blue line which is represented the active suspension with AFC scheme.

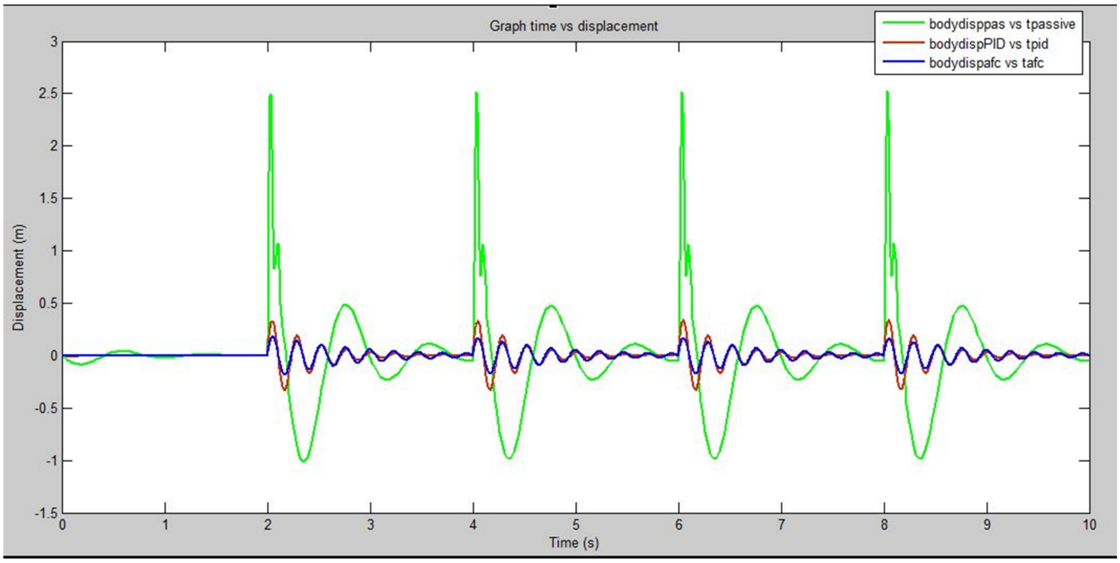

Figure 4.8: Graph displacement versus time for passive suspension and active suspension with repeating sequence input.

4.2.4 Analysis of Passive Suspension versus Active Suspension System with Pulse Generator Input.

Next input used for the simulation is pulse generator with amplitude of 0.1m and period of 2 sec. Figure 4.9 shows that the sprung mass displacement for active suspension has a reduction up to 150% in the amplitude by considering peak-to-peak values compared to the passive suspension and exhibits a marked of 30% reduction compared to active suspension with PID controller.

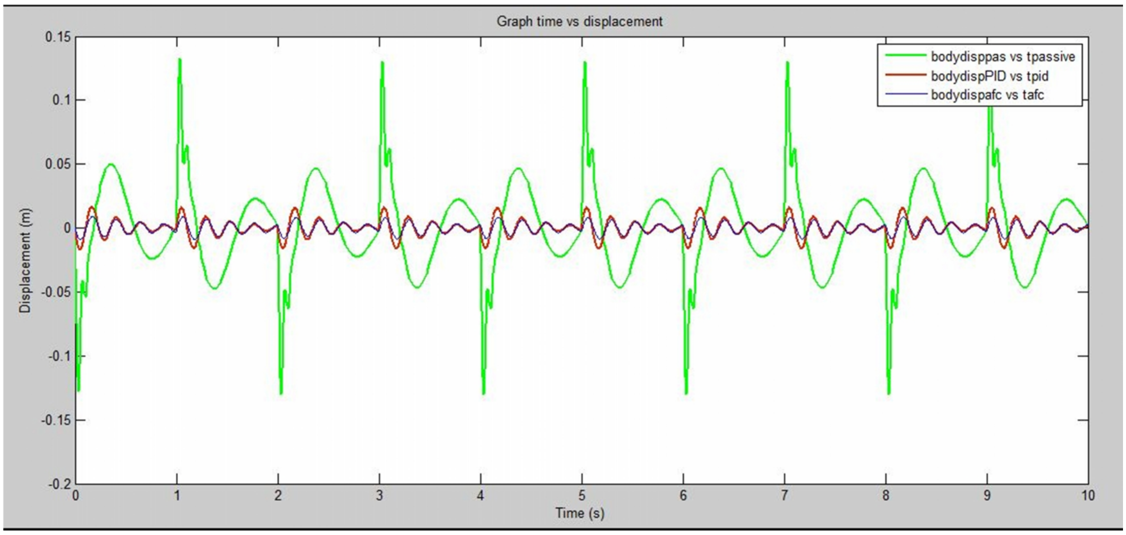

Figure 4.9: Graph displacement versus time for passive suspension and active suspension with sinusoidal input.

From the simulation results and analysis, it was found that the active suspension with AFC system outperforms the active suspension with PID controller and passive suspension. It also shows that AFC system is the most robust, stable and effective control scheme compared to other suspension system. So its achieved the objective of the study. This clearly demonstrates the robustness and potential practical of AFC scheme in real life.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

All the work progress has been show clearly in the previous chapter including the design process, simulation result and analysis of passive suspension, active suspension with PID controller and active suspension with AFC. In this chapter, all of the research and simulation results will be summarized. The performance of the suspension system are evaluated and compared to each other. The recommendation will be proposed for better improvement for the next invention.

5.2 CONCLUSION

This report shows the control loop design and simulation of AFC controller on active suspension system. The main purpose of using AFC controller on active suspension system was to allow both comfort and minimize the vibration compared to the passive suspension system.

As for the conclusion, all objectives for this research were achieved. From the simulation results, it showed that active suspension with AFC scheme was the best system in surpass the vibration compared to active suspension with PID controller and passive suspension system. Active suspension with AFC scheme always has a lowest body sprung displacement compared to passive suspension and active suspension with PID controller. The values of the controller parameters may influence the system dynamic behaviour as different conditions and settings may result in undesirable response. This AFC system could provide significant improvement in decreasing the sprung mass (body) displacement and improving vehicle riding.

5.3 RECOMMENDATIONS

For the future research, my recommendation is to do an analysis of AFC system in surpass the vibration with both simulation and experiment setup. So that we can analyse this 2 result to make sure it match each other.

Next recommendation is to study about spring deflection and influence of cornering on vehicle roll with active suspension system. Research with half car or full car models also recommended. This high order of multi-degree-of-freedom model involving many suspension parameters and design to analyse the performance of the suspension system.

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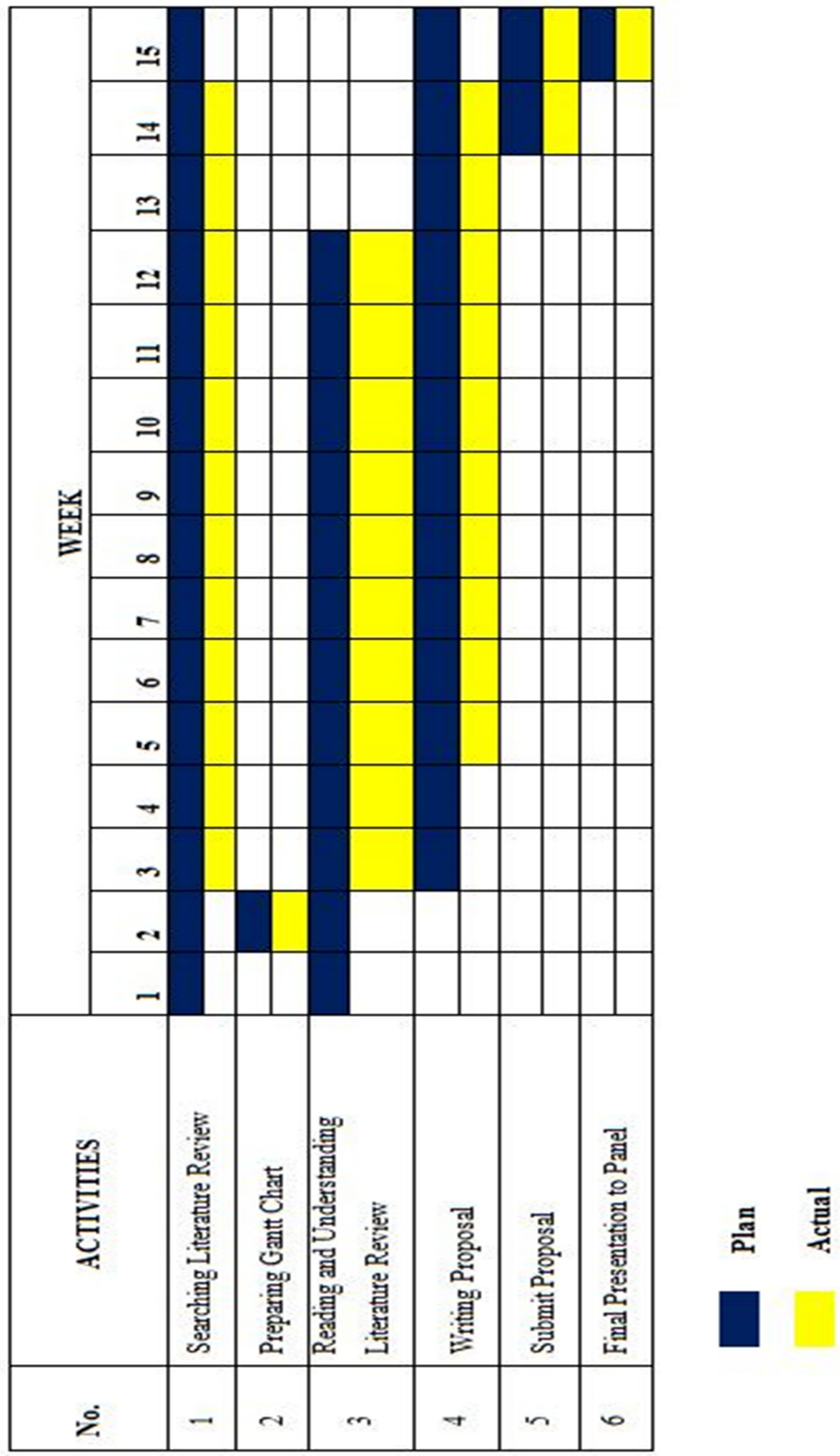
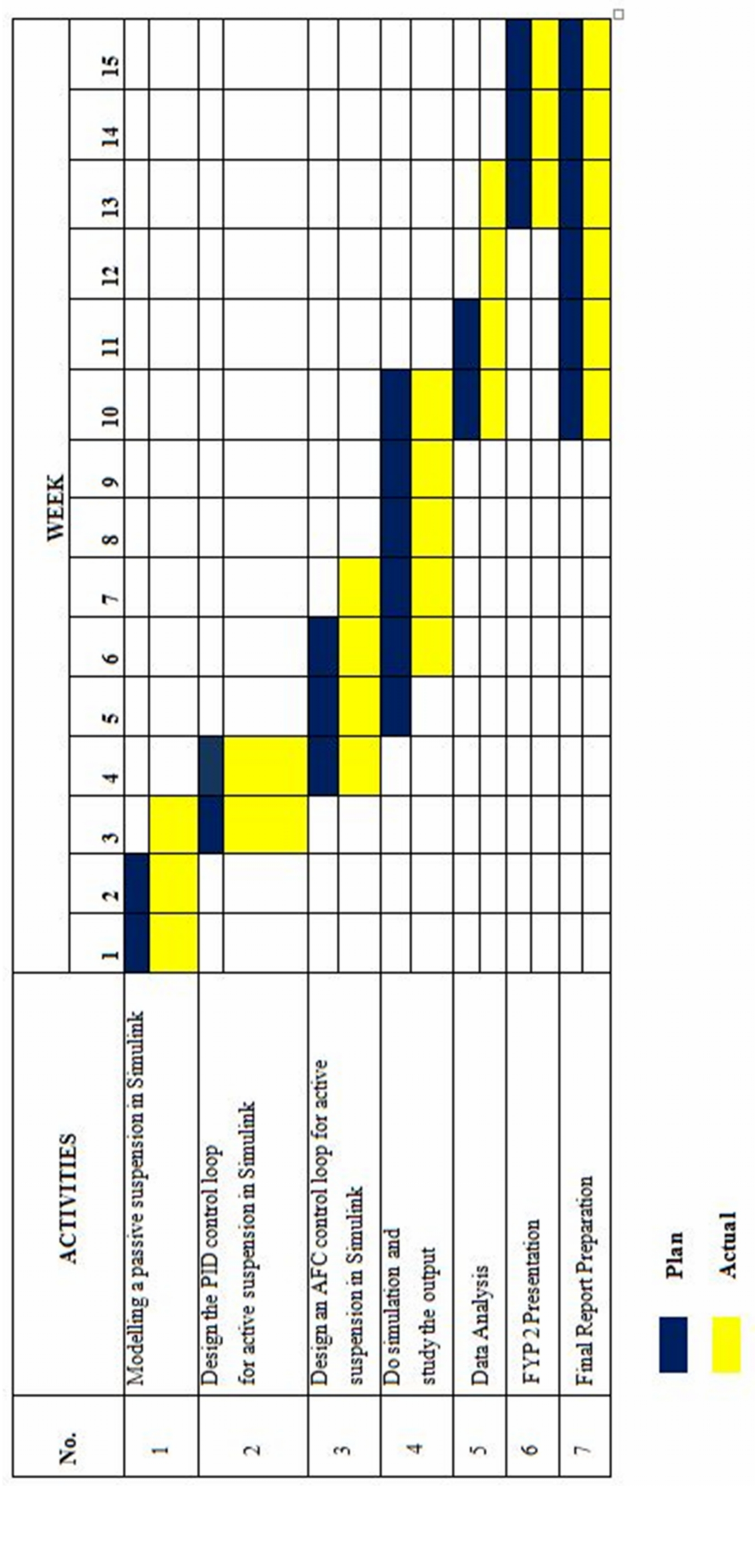
APPENDICES A1: GANTT CHART FYP 1



APPENDICES A2: GANTT CHART FYP 2



APPENDICES B : SIMULINK LIBRARY