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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

ACTIVE SUSPENSION CONTROL USING MULTIORDER PID CONTROLLER

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Master of Mechanical Engineering (Automotive)

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ACTIVE SUSPENSION CONTROL USING MULTIORDER PID CONTROLLER

MOHD RASYIDI BIN RIDZUAN

A report submitted
in fulfillment of the requirements for the degree of
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Faculty of Mechanical Engineering

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DECLARATION

I declare that this report entitle "Active Suspension Control using Multiorder PID Controller" is the result of my own research except as cited in the references. This report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MOHD RASYIDI BIN RIDZUAN

Date : 14 NOVEMBER 2016

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APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfilment of Master of Mechanical Engineering (Automotive)

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14 NOV 2016

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DEDICATION

To my beloved mother, father, my wife, son and daughter

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ABSTRACT

This study investigates the propose controller for active suspension system to improve ride comfort of the vehicle. The main content of this study is the development and application of the multiorder Proportional-Integral-Derivative (MOPID) control scheme, and the investigation of the control system ability to provide improvement in vehicle ride comfort. The multiorder Proportional-Integral-Derivative (MOPID) are arranged in a separated control loops called the outer loop controller, which is used to amplify the disturbance from the road input and reduce unnecessary vehicle motions and the inner loop controller that is produced the signal to the active suspension system to produce the force by force actuator. The performance of the proposed controller is compared to the conventional PID controller and the passive suspension system. Simulation studies are shown in time domain simulation produce from Matlab/Simulink software. From the simulation, it shows that the proposed control scheme is able to provide improvement in terms of body vertical displacement and body vertical acceleration. The development of the multiorder PID is also easy to implement in practice based to its simple controller structure.

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ABSTRAK

Kajian ini adalah berkenaan sistem kawalan yang dicadangkan untuk sistem suspensi aktif untuk meningkatkan keselesaan perjalanan kenderaan. Kandungan utama kajian ini ialah pembangunan dan penggunaan sistem kawalan berperingkat perkadaran-integrasi-terbitan (MOPID), dan penyelidikan pada keupayaan sistem kawalan untuk menyediakan peningkatan dalam keselesaan perjalanan kenderaan. sistem kawalan berperingkat perkadaran-integrasi-terbitan (MOPID) disusun dalam gelung kawalan berasingan dipanggil gelung pengawal luar, yang digunakan untuk mengawal gangguan dari input jalan raya dan mengurangkan pergerakan yang tidak perlu pada kenderaan dan pengawal gelung dalaman yang memproses isyarat kepada sistem suspensi aktif bagi menghasilkan daya melalui penggerak. Prestasi pengawal yang dicadangkan dibandingkan dengan pengawal perkadaran-integrasi-terbitan (PID) konvensional dan sistem penggantungan pasif. Kajian simulasi ditunjukkan melalui masa simulasi domain hasil daripada perisian Matlab/Simulink. Dari simulasi, ia menunjukkan bahawa skim kawalan yang dicadangkan mampu memberikan peningkatan dari segi anjakan menegak badan dan pecutan menegak badan. Pembangunan sistem kawalan berperingkat perkadaran-integrasi-terbitan (MOPID) ini juga mudah untuk dilaksanakan dalam amalan berdasarkan kepada struktur kawalan yang mudah.

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LIST OF SYMBOLS

C_s - Stiffness value of the passive damper

e - Errors

e_z - Body displacement errors

$e_{\dot{z}}$ - Body velocity errors

$e_{\ddot{z}}$ - Body acceleration errors

F_p - Augmented force from the actuator

K_I - Integral Constant

K_P - Proportional Constant

K_D - Derivative Constant

K_s - Stiffness value of the passive spring

K_T - Stiffness value of the tire

L - Stroke length of the piston

M - Mass of the pneumatic piston

M_u - Mass of the wheel axle (unsprung mass)

M_s - Mass of the vehicle body (sprung mass)

RMS - Root Mean Square

Z_u - Vertical displacement of the wheel axle

Z_s - Vertical displacement of the vehicle body

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Z_r	-	Vertical displacement of road profile
$\dot{Z}_u$	-	Vertical velocity of the wheel axle
$\dot{Z}_s$	-	Vertical velocity of the vehicle body
$\dot{Z}_r$	-	Vertical velocity of road profile
$\ddot{Z}_u$	-	Vertical acceleration of the wheel axle
$\ddot{Z}_s$	-	Vertical acceleration of the vehicle body
$r_{(t)}$	-	Reference input signal
$e_{(t)}$	-	Error Signal
$u_{(t)}$	-	Input signal to the plant model
$d_{(t)}$	-	Disturbance
$y_{(t)}$	-	Output signal
DOF	-	Degree of Freedom

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Active suspension has attracted many researchers to study and develop a new way of solution to bring the most ideal vehicle suspension. Related research about active suspension are publish by Sarma and Kozin (1971), Sutton (1979), Margolis (1982), Yoshimura et al. (1986), Yamashita et al. (1990) and Lin and Lian (2011). All this research explains about the system in suspension of the vehicle that can be categories in 3 systems such as vehicle passive suspension system, vehicle semi-active suspension system and most advance vehicle active suspension system.

The vehicle passive suspension system, the system only contain by the spring that support the weight of the vehicle and the absorber that absorb the vibration and oscillation of the suspension movement. For the system in vehicle active suspension, we can see the spring that support the weight of the vehicle and the absorber to absorb the vertical movement of the vehicle are takeover by actuator whether in fully or by partial of the system. These actuator will operate to buildup force to counter the road surface movement by calculate and control the reaction from the movement of the vehicle suspension system.

Vehicle semi-active suspension systems are develop and be produce from the vehicle active suspension system by replace the use of actuator as force builder to the damper that can be controlled the movement of the vehicle and the spring to support thr weight of the vehicle. Semi-active suspension system is only capable of dissipating energy at a variable rate by adjusting the damping force (Williams, 1994). The adjustable damping

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characteristic can be accomplish by apply an adjustable damper with the appropriate control strategy. The simplicity of the control structure of semi active suspension yields that the controller can run on a low-cost system. Swevers et al. (2007). There are two different pattern of damper that been used in the vehicle semi-active suspension known as adjustable orifice damper and magnetorheological damper.

1.2 Problem Statement

The vehicle suspension system brings a major task in order to maintain vehicle driving performance and comfort. The studies for the front vehicle suspension system are very important to improve the vehicle performance in order to keep the vehicle in control and bring the comfort of driving. To enhance these criteria, many researchers come with the solution with introduction of active suspension component. The active suspension has a very wide function in order to absorb varies of driving condition and road profiles.

Vehicle suspension system is the structure on vehicle that connects the wheel and the body of the vehicle. The function of this system is to isolate the vehicle body with the road surface profile in order to maintain the ride comfort. Another function of the vehicle suspension is to keep the vehicle in control.

The primary function of the vehicle suspension can be achieve by using spring as a malleable component combine with damper as a force absorption component. An another function can be accomplish by manage the motion of the suspension system and wheel assembly using the mechanical link.

Vehicle suspension system needs to hold several type of vehicle dynamics aspect. For achieving optimum ride comfort, it needs to keep to minimum the vertical body acceleration of the suspension system and good dynamics performance needs an optimum road contact so it needs to contain the normal force between road and tyres in all

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conditions. It's all needs to working in vehicle body acceleration and vehicle body displacement. The disadvantages of the passive system are it needs to gain other performance but to sacrifice other performance area. To develop the vehicle suspension system that can give both ride comfort and handling performance, the reliance on vehicle passive suspension is irrelevant. This problem can be overcome by developing an active suspension system.

By combining the passive suspension component and force actuator that been control by a controller that sense by a sensor, the active suspension system work efficiently in order to reduce vertical body acceleration, reduce body vertical displacement and overall improve the ride comfort and handling performance of the vehicle.

Sensor in active suspension system play a major in detect the body displacement and body acceleration, the signal then is used by the controller to analyse the condition and measure what type of feedback to be send to the actuator. The force actuator receives the processed signal from the controller that contain how much force its need to control the active suspension system. This will form a closed loop system. The data from the closed loop system will be compared with the open loop system to measure the performance of active suspension system.

For this research, the aim is to design and analyse the proposed control system for the body vertical displacement and body vertical acceleration of proposed vehicle active suspension system. The control system will be implemented via a suspension active suspension system that consists of spring, damper and a force actuator. The forces between upper sprung mass and below unsprung are implement by a controller signal. The controller is design through simulation studies which compare between Proportional Integral Derivative (PID) Controller and multiorder Proportional Integral Derivative Controller (MOPID) in order to compare the best output. The result of the output signal is

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then compared with passive suspension system. Performance criteria to be evaluated in this research is the ability of the multiorder PID controller in reducing vertical sprung mass acceleration and suspension travel displacement to compare with passive suspension system and Proportional Integral Derivative (PID) active suspension system.

1.3 Research Background

They are many controllers that have been used in a research of a controller in active suspension system. The controllers may be divided into 3 groups of control strategies named linear controller, nonlinear controller and intelligent controller. The linear controller is mainly focus on optimal control theory such as Linear Quadratic Gaussian (LQG), Linear Quadratic Regulator (LQR) and Loop Transfer Recovery (LTR) that can reducing the performance indication but this type of controller have a less function of processing the variation of data and road profile (Sam *et al.* 2006). Based on the past study, the nonlinear controller use such as sliding mode control (SMC) and an adaptive controller have come out with the good result. However the main problem is this type of controller is unstable. The study on intelligent controller shows that this type of controller brings promising result but with the tradeoff of stability problem. For the study purpose, the stability characteristics usually been ignored in the design of the controllers. Even all these controllers are proof to be effective in controlling the active suspension; PID control method is selected to be used in these studies. PID controller based is chosen because the controller is easy to operate and sustain in controller hardware and already proven by many researchers.

To study the performance and behavior of vehicle active suspension using PID and multiorder PID controller, the MATLAB/Simulink software used. The result of the active suspension is then compared with the data from passive suspension system.

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1.4 Objectives and Scope of Research

The objectives of this research are defined as follows:

1. To simulate and validate a model of two degree of freedom (2 DOF) quarter car suspension system.
2. To develop a PID and multiorder PID controller using Matlab/Simulink.
3. To study the performance of PID active suspension and multiorder PID active suspension signal.

The scope of this research covers the followings:

1. This study is focus on the controller's capabilities to reduce body vertical displacement and acceleration by using Matlab/Simulink simulation.
2. This study is using two degree of freedom (2 DOF) quarter car model. The tyre is show as a true spring without damper effect. The motion of rotational in body and is neglected. The movement of wheel and body are assumed perfectly vertical. The action of spring and damper are simulated as linear.
3. Only ride comfort analysis is performed.
4. The performance of the controller is investigated on the capability to attenuate the effects of road induced disturbances.
5. The simulation is carried out using Matlab/Simulink and the quarter car model is validated with the result from (Imaduddin, 2010).

1.5 Methodology

The step of methodology that been used in this research is described as the following stage of works:

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1. Modelling and validation of two degree of freedom (2 DOF) active suspension quarter car model.

This research started with the development of a quarter car suspension model to describe analytically the dynamic behaviour of a quarter car model in vertical direction. For this purpose, a 2 degree-of-freedom (DOF) quarter vehicle active suspension model is simulated.

2. Control design by simulation of active suspension and PID controller

Simulation study on the performance of the active suspension system along with the PID controller for vehicle comfort was also been investigated. The main activity in this stage is to assess the capability of active suspension with PID controller to increase vehicle comfort compare to passive suspension system.

3. Control design by simulation of active suspension and multiorder PID controller

As the capability of PID controller in usage as the controller of active suspension system has been established, this study proceeds with the enhanced controller design. Multiorder PID were designed and the performance were assess on a two degree of freedom (2 DOF) quarter car model as par as normal suspension usage. Performance evaluation of the control strategies were evaluate by the capability of the multiorder PID controller in order to increase ride comfort better than active suspension system controlled by PID controller.

4. Performance evaluation of active suspension controllers

The concluding stage in this research was the simulation of the performance on the vehicle active suspension controller. All the simulation studies in normal

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suspension behaviour and evaluate between passive suspension behaviour, vehicle active suspension with the implementation of PID controller and active suspension with the implementation of multiorder PID controller. The simulation result will then be compared and performance between simulations will be evaluated.

1.6 Project Report Outline

This project report consists of five chapters. Chapter 1 is the introduction chapter. This chapter presents the problem statement, the research background, objectives and scopes of the study, methodology of research, and the outline of this thesis

Chapter 2 presents the literature review on the subjects regarding this thesis. In this chapter, the type of vehicle suspension system, the actuator types and the type of control strategies for active suspension system are described.

Chapter 3 presents the methodology of the studies on quarter car model suspension model and the controller design. In this chapter, the mathematical equation of 2DOF quarter car model is discussed and the validation parameter of quarter car test model is presented by using the data from (Imaduddin. 2010). Then the designs of proposed PID controller and multiorder PID controller are explained.

Chapter 4 describes the result and discussion of the validation of quarter car suspension model from the simulation and the data from (Imaduddin. 2010) and the performance comparison of the proposed controllers. In this chapter, the validation of the 2 DOF quarter car suspension model is compare with the data from (Imaduddin. 2010) and discussion is focus on the pattern of the validation graph. Then the simulation analysis on the frequency domain and time domain of the proposed PID controller and multiorder PID control structure are presented and a compared with passive suspension system.

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