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Faculty of Mechanical Engineering

MULTI-ORDER PID CONTROLLER DESIGN FOR ACTIVE ANTI-ROLL SUSPENSION SYSTEM

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MULTI-ORDER PID CONTROLLER DESIGN FOR ACTIVE ANTI-ROLL SUSPENSION SYSTEM

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A thesis submitted
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2017

DECLARATION

I declare that this thesis entitled " Multi-order PID Controller Design for Active Anti-Roll Suspension System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : FATHIAH BT MOHAMED JAMIL

Date : 23/2/2017

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Automotive Engineering)

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Supervisor Name : DR.MOHD AZMAN BIN ABDULLAH

Date : 21/06/2017

DEDICATION

I would like to give a very special appreciation to my beloved friends and family for always been there in the time of need. Thank you for giving me continous support in order for me to fulfill the needs of my Master Project. To my beloved mother, father, family and friends, thank you all for this.

ABSTRACT

This paper focusing on investigation of multi-order Proportional-Integral-Derivative (MOPID) controller for active anti-roll suspension system in order to provide ride comfort and stability while handling the vehicle on uneven road surface. Development of the MOPID has been arranged and tested on 4DOF half car model in order to increase ride comfort and improve vehicle controllability. MOPID work in a separate loop where the outer loop increase the disturbance from the road (input) and the signal that has been sent to the active suspension system through inner loop that controlled by force actuator that act in reducing the unnecessary vehicle motion. The performance comparison has been made between passive suspension and active anti roll suspension by using Matlab/Simulink (active suspension) and CarSim work as a reference for simulation studies of passive suspension. The different can be seen after MOPID has been applied to the active anti roll suspension system. Its shows that MOPID create a better system which work much more better by providing vehicle stability, good controllability and ride comfort. It's also give an improvement on vehicle handling in term of body displacement and body roll. Thus, the development of this controllers is important besides its structure is simple and easy in practice.

ABSTRAK

Kajian ini memberi tumpuan kepada penyiasatan keatas suspensi aktif anti gulungan menggunakan sistem kawalan berperingkat perkadaran-integrasi-terbitan (MOPID) untuk menyediakan keselesaan perjalanan dan kestabilan semasa mengendali kenderaan di atas permukaan jalan yang tidak rata. Pembangunan MOPID ini telah diatur dan diuji pada model separuh kereta untuk meningkatkan keselesaan perjalanan dan memperbaiki keupayaan pengendalian kenderaan. MOPID bekerja dalam gelung yang berasingan di mana gelung luar meningkatkan gangguan dari jalan (input) dan isyarat yang telah dihantar ke sistem suspensi aktif melalui gelung dalaman yang dikawal oleh daya penggerak yang bertindak untuk mengurangkan pergerakan kenderaan yang tidak perlu. Perbandingan prestasi telah dibuat antara suspensi pasif dan suspensi aktif anti gulungan dengan menggunakan perisian Matlab / Simulink (suspensi aktif) dan perisian CarSim sebagai rujukan kajian simulasi bagi suspensi pasif. Perbezaaan boleh dilihat selepas MOPID digunakan untuk melancarkan sistem suspensi aktif anti gulungan. Keputusan menunjukkan bahawa MOPID mewujudkan satu sistem yang menyediakan kestabilan pada kenderaan, kawalan kenderaan yang baik dan keselesaan perjalanan. Ia juga memberi peningkatan keatas pengendalian kenderaan dari segi anjakan badan dan gulungan badan. Oleh itu, pembangunan sistem kawalan ini adalah penting di samping struktur yang mudah untuk di gunakan.

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LIST OF SYMBOLS

SYMBOLS	DESCRIPTION
K_P	Proportional Constant
K_I	Proportional Constant
K_D	Derivative Constant
Z_b	Left Sprung Mass Center of Gravity Displacement
$\dot{Z}_b$	Left Sprung Mass Center of Gravity Velocity
$\ddot{Z}_b$	Left Sprung Mass Center of Gravity Acceleration
$\emptyset$	Sprung Mass Pitch Angle
$\dot{\emptyset}$	Sprung Mass Pitch Velocity
$\ddot{\emptyset}$	Sprung Mass Pitch Acceleration
$I_{\emptyset}$	Inertia in yaw direction
k_{sl}	Left Spring Stiffness
k_{sr}	Right Spring Stiffness
k_{tl}	Left Tire Stiffness
k_{tr}	Right Tire Stiffness
C_{sl}	Right Damper stiffness
C_{sr}	Left Damper stiffness
Z_{rr}	Right Road Input to Wheels
Z_{rl}	Left Road Input to Wheels
Z_{wr}	Displacement of Unsprang Mass (Right)
$\dot{Z}_{wr}$	Velocity of Unsprang Mass (Right)
Z_{wl}	Displacement of Unsprang Mass (Left)

$\dot{Z}_{wl}$	Velocity of Unsprung Mass (Left)
Z_{bl}	Left Sprung Mass Center of Gravity Displacement
$\dot{Z}_{bl}$	Left Sprung Mass Center of Gravity Velocity
Z_{br}	Right Sprung Mass Center of Gravity Displacement
$\dot{Z}_{br}$	Right Sprung Mass Center of Gravity Velocity
t	Track
m_b	Kerb Weight
F_{ar}	Right Actuator Force Control
F_{al}	Left Actuator Force Control
$u(t)$	Input signal to the plant model
$e(t)$	Error Signal
$d(t)$	Disturbance
e_z	Error signal of vertical body displacement
$e_{\dot{z}}$	Error signal of vertical body velocity
$e_{\ddot{z}}$	Error signal of vertical body acceleration
e_r	Error signal of angular body displacement
$e_{\dot{r}}$	Error signal of angular body velocity
$e_{\ddot{r}}$	Error signal of angular body acceleration
RMS	Root Mean Square
DOF	Degree of Freedom

CHAPTER 1

INTRODUCTION

1.1 Introduction

The need for passenger comfort, road handling abilities of tires, vehicle handling characteristics, have been the major challenge in the design of suspension system over the years. However, the ride comfort is the main concern in order to give comfort feeling of the passengers in the running conditions and arises from various sources of vibrations of the vehicle body which comes from the road surface irregularities. However, vertical displacement and vehicle acceleration caused by roll motions and pitch give an effects both on vehicle comfort and driving safety [1].

Suspension systems work to give an offer for better vehicle ride handling and increase vehicle stability. The amplitude acceleration of sprung mass might be suppressed and the deflection of the tire can be reduced. It will improve efficiently the above mentioned features. In general, suspension systems can be categorized into three groups which are the passive suspension, semi-active suspensions and active suspensions. Moreover, there is a characteristic in passive suspension system where the damper and springs are fixed. These physical characteristics are classified based on the design goals and the intended application. The energy dissipating element in passive suspension is like energy storing element, damper and spring.

In the year 1970's semi-active suspension systems has been first proposed. The conventional spring element is retained in this kind of system but the controllable damper was used as a replacement of damper itself. To change the damping levels and drive an embedded controller, an external power is required. Thus, the passive suspension system is simpler compared to the fully active suspension system which performs with the high cost.

Active suspension is one of a new technology that has been developed and widely used in modern cars. The body vertical vibration can be prevented with an active force produce by an actuator and its characteristic straightly affects the vehicle's comfort, stability and safety [2]. In active suspension system, the body vibration which is developed due to the uneven road surface and from the carrier system can be suppressed with the help of actuator. Furthermore, the amount of suspension deflection was affected by the vehicle structural features which help in reducing car body acceleration. A higher level of suspension are reachable by designing suspension which can control and focus on minimizing car body acceleration and the suspension deflection is small and approached its limit. Moreover, an active suspension control not only can offer good vibration isolation for the sprung mass to improve pitch, roll and have response of the vehicle body but also can achieve better handling stability in critical maneuvering, accelerating and braking [3]

1.2 Problem Statement

Suspension system plays an important role to allow the vehicle weight, to cut off the vehicle body from road instabilities and to preserve the traction force between the tire and the road surface. Most of the suspension system include springs and dampers as conventional passive elements. The vehicle suspension consists of the shock absorber to transmit all forces between body and road, wishbones, and the spring carries the body mass and separates from road disturbances. Moreover, it also involves concerning inconsistent propositions. The vehicle body must be well isolated from the road surface irregularities. In addition, the deflection of suspension must remain as small as possible to control and handle vehicles on road. Therefore, in order to improve both ride comfort and good handling performance, there are many experimental and analysis studies have been done on active suspensions.

Passive suspensions comply with the comfort, security, and stability but mainly decrease in comfort as this type of suspension is not possible to modify its actuators as they present the shortcomings of the way. But, an improvement on passive suspension system can be made and come with an active suspension with multi PID controller in order to achieve those goals. An active suspension will work effectively by combining the passive suspension component and force actuator sensor in order to decrease body vertical displacement and acceleration and also angular body displacement and velocity. So that, it will improve the ride comfort and stability of the vehicle.

The trade-off between handling and ride is one of the problems that recently has been discussed among researchers and it is strongly related to an active anti-roll suspension systems performance. The control system has been proposed will give an advantage to the adjustable damper and the controlling the vehicle body roll with the development of an electric active stabilizer suspension system to enhance the control performance [4]. Thus, the sensor in active suspension system act as an indicator to the vehicle body displacement and acceleration. The type of response that will drive back to the actuator depends on the condition after the input has been analyzed and measured. Then, the signal from the controller will send to the force actuator and it will determine how much force it needs to control the suspension system.

In this research, the objective of this study is to design and proposed of multi-order PID controller on active anti roll suspension system and how it give effects on the vertical and angular movement of vehicle body. Spring, damper and force actuator are the main component of active suspension and the control system will be applied on it. The control signal that has been implemented will provide forces between upper sprung mass and below unsprung. The best output comparison between Passive Suspension and Multi-order Proportional Integral Derivative Controller (MOPID) are based on how the controller will be design and implement. The ability of the MOPID controller performance need to be evaluated in this research on how it can reduce vertical body acceleration, vertical body displacement, angular body displacement and also angular body velocity.

1.3 Research Background

Few methods of the controller that have been designed related to an active suspension system and it’s have been suggested to improve the handling ability and the riding ease of cars. However, the mathematical model is too difficult to identify its controller design when an active suspension system has nonlinear and undefined characteristics. In order to improve the ride comfort and life of the system structure, the acceleration and amplitude of vibration of the sprung mass must be suppressed effectively.

Several strategies have been suggested and developed to control the suspension system performance. There are three groups of control strategies involve in controlling suspension system which are linear controller, nonlinear controller, and intelligent controller

1.4 Objectives of Research

The objectives of this research are:

1. To simulate and verified of four degrees of freedom (4 DOF) half car suspension system model.
2. To design multi-order PID controller using Matlab/Simulink.
3. To analyze the stability of vehicle performance by implementing multi order PID controller

1.5 Scope of Research

The scope of this research covers the followings:

1. This research is emphases on the controller abilities to reduce body vertical displacement, body acceleration, angular displacement and also angular velocity by using Matlab/Simulink simulation software.
2 Four degrees of freedom (4 DOF) half car has been modeled and used in this study. The system works as an active anti-roll suspension system. The tires will be attached to the system which has spring, damper effect and force actuator. The rotational motion in a body is included (roll).
3 Performed only ride comfort and stability analysis.
4 The controller performance is examined on its capability to reduce the effects of road disturbances
5 The half car model is verified with the result from CarSim through simulation that is carried out using Matlab/Simulink

1.6 Methodology

There are a few steps of methodology that been applied in this research and it is described as below:

1. Modeling and verification of four degrees of freedom (4 DOF) roll suspension system. The development of a half car suspension has been modeled by using Matlab/Simulink in order to describe the dynamic behavior of a half car model in the vertical and angular body (roll) direction. Therefore, four degrees of freedom (DOF) half car roll suspension model has been simulated and analyzed for this purpose.

2. Simulation on control design by simulation of active anti-roll suspension with multi-order PID controller

   Multi-order PID controller was designed and simulated by using Matlab/Simulink software. Then, its performance was tested on a four degree of freedom (4 DOF) half vehicle model as similar as normal suspension usage. As the capability of PID as a controller of active suspension system has been recognized, thus the advance controller design has been studied. The control strategies were evaluated on its capability in reducing body displacement and angular velocity in order increase the ride comfort and vehicle stability.

3. Performance evaluation of active anti-roll suspension with controllers

   The final stage in this research was performance verification between the passive suspension system and active anti-roll suspension with multi-order PID controller. Normal