SIMULATION AND EXPERIMENTAL EVALUATION ON SLIDING MODE CONTROL FOR PNEUMATICALLY ACTUATED ACTIVE SUSPENSION SYSTEM USING QUARTER CAR TEST RIG

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“I admit that I have read this research and from my opinion this research is good enough in term of scope and quality for the purpose to award the Bachelor in Mechanical Engineering (Automotive).”

Signature :

Supervisor I Name :

Date :

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DECLARATION

"I admit that this report is from my own work and idea except for the summary and a few sections which were extracted from other resources as being mention"

Signature :

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Date : 8 MAY 2009

DEDICATION

Special for family, my friends and my Project Supervisor, Dr.Khisbullah Hudha.

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All praises be to God, The Most Gracious, The Most Merciful for His Guide and blessing.

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ABSTRACT

The purpose of this project is to investigate the performance of using sliding mode control in controlling the active suspension system. The controller system that will be used is the proportional-integral sliding mode control (PISMC) scheme. A quarter-car model is used in the study and the performance of the controller is compared with the existing passive suspension system. A simulation study using MATLAB software and experiment on quarter car test rig will be performed to prove the effectiveness of this control approach.

ABSTRAK

Tujuan utama projek ini dijalankan adalah untuk mengkaji keupayaan menggunakan *sliding mode control* untuk mengawal sistem suspensi aktif. Sistem kawalan yang akan digunakan adalah *proportional-integral sliding mode control* (PISMC). Model untuk suku kereta akan digunakan dalam melaksanakan projek ini dan prestasi sistem kawalan ini akan dibandingkan dengan sistem suspensi pasif sedia ada. Kajian simulasi akan dijalankan dengan menggunakan perisian MATLAB dan eksperimen akan dilakukan keatas model satu perempat kereta untuk membuktikan keberkesanan kawalan yang digunakan dalam projek ini.

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M_s	=	mass of car body, kg
M_{us}	=	mass of wheel, kg
x_s	=	displacements of car body
x_{us}	=	displacements of wheel
K_a	=	spring coefficient of the suspension system, N/m
K_t	=	spring constant of the tyre, N/m
C_a	=	damping coefficient, Nsec/m
$\dot{r}$	=	road disturbance

LIST OF ABBREVIATION

PISMC	Proportional-Integral Sliding Mode Control
MATLAB	Matrix Laboratory
PI	Proportional-Integral
RMS	Root Mean Square
LVDT	Linear Variable Differential Transformer
IMC	Internal Model Control
NetBEUI	NetBIOS Extended User Interface
FAMOS	The Framework for Adaptive Modeling and Ontology-driven Simulation

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CHAPTER I

INTRODUCTION

1.1 Objective

The main objective of this project is to investigate the performance of sliding mode control for pneumatically actuated active suspension system using quarter car model. Other objectives are to study the structure of sliding mode control and experimentally investigate its performance for controlling pneumatically actuated active suspension system using quarter car test rig.

1.2 Scope

The scopes for this project are to create a controller design for pneumatically actuated active suspension system by using sliding mode approach. The performance evaluation of this design will first be tested on computer simulink by using MATLAB software, and then the experiment will be done using the quarter car test rig.

1.3 Problem statement

The main objective of this project is to improve the riding characteristics of a vehicle by using the active suspension system to replace the existing passive suspension system that has been used in normal vehicle since decade. Active suspension is an automotive technology that controls the vertical movement of the wheels through a control system rather than the movement being determined entirely by the surface on which the car is driving. This system will virtually eliminates body roll and pitch variation in many driving situations including cornering, accelerating and braking.

This active suspension system is different from passive suspension system in term of having a pneumatic actuator to support force for the active suspension system. The pneumatic actuator will be control by a controller that will be created and test in this project. The control that will be evaluated in this project is the Proportional-Integral Sliding Mode Control. This technology allows car manufacturers to achieve a higher degree of both ride quality and car handling by keeping the tires perpendicular to the road in corners, allowing for much higher levels of grip and control.

1.4 Project Overview

In this project, the control scheme that has been chosen to improve the ride comfort and road handling of the active suspension system is the sliding mode control. Even though there are various control strategies such as optimal state feedback, backsteeping method, optimal state feedback, fuzzy control and sliding mode control that can be choose to control the system, we have choose the sliding mode control because it has relatively simpler structure than others and it guarantees the system stability. The sliding mode control in this project is based on the proportional-integral sliding mode control (PISMC).

A computer simulation using MATLAB software will be performed to demonstrate the effectiveness of the proposed control scheme. The simulink model will be created by referring the quarter car suspension system and PISMC equation. The control system then will be test experimentally on quarter car test rig to get the real result and the performance evaluation of this project.

CHAPTER II

LITERATURE REVIEW

2.1 Dynamic Model of a Quarter Car Suspension System

For this project, quarter car model is used to determine the effectiveness of the suspension (Yahaya and Hudha, 2006 **)**. The quarter car model for passive suspension system consists of one-fourth of the body mass, suspension components and one wheel as shown in Figure 2.1 (a). The quarter car model for active suspension system, where the pneumatic actuator is installed in parallel with the spring and the passive damper, is shown in Figure 2.1 (b).

The assumptions for the quarter car modelling are as follows:

- The tyre is modelled as a linear spring without damping
- There is no rotational motion in wheel and body
- The behaviour of spring and damper are linear
- The tyre is always in contact with the road surface
- The effect of friction is neglected so that the residual structural damping is not considered into vehicle modeling.

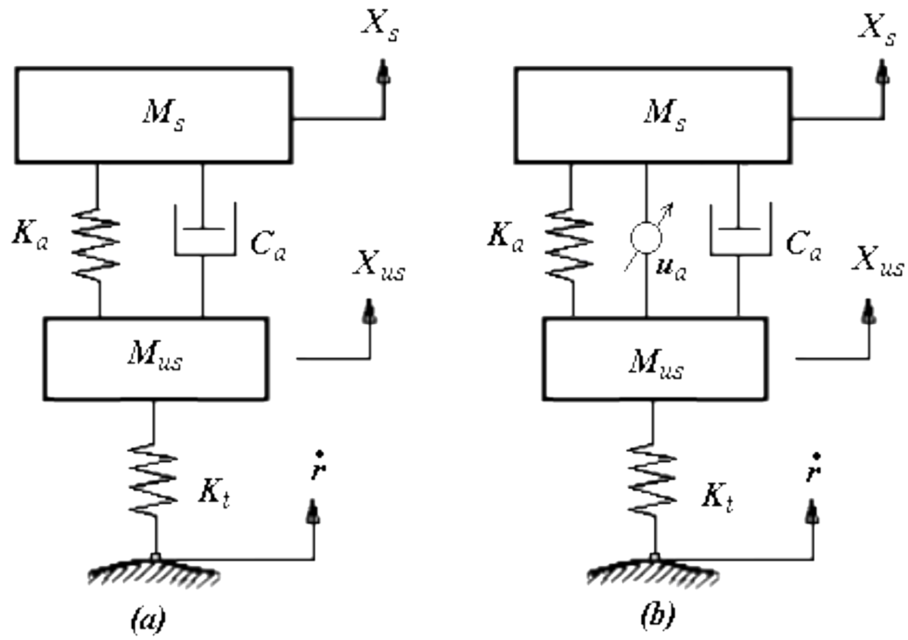

Figure 2.1 : Quarter car suspension model

The equations of motion for the sprung and unsprung masses of the active quarter car model are given by the following state space representation

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -K_a/M_s & -C_a/M_s & 0 & C_a/M_s \\ 0 & 0 & 0 & 1 \\ K_a/M_{us} & C_a/M_{us} & -K_t/M_{us} & -C_a/M_{us} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 1/M_s \\ 0 \\ -1/M_s \end{bmatrix} u_a + \begin{bmatrix} 0 \\ 0 \\ -1 \\ 0 \end{bmatrix} \dot{r} \quad (1)$$

Where U_a is the control force from the pneumatic actuator and assumed as the control input. For the passive suspension system, U_a =0. Equation (1) can be written as

$$\dot{x}(t) = \mathrm{A}x(t) + Bu(t) + f(t) \quad (2)$$

M_s and M_{us} are the masses of car body and wheel respectively, x_s and x_{us} are the displacements of car body and wheel respectively, K_a is the spring coefficient of the suspension system, K_t is the spring constant of the tyre, C_a is the damping coefficient and $\dot{r}$ is the road disturbance. The following terms are defined as the state variables: x_1= x_s-x_{us} for suspension travel $x_2 = \dot{x}_s$ for car body velocity, x_3= x_{us} - r for wheel deflection and $x_4 = \dot{x}_{us}$ for wheel velocity.

2.2 Switching Surfaces and Controlling Design.

The controller structure used in this is the proportional integral sliding mode controller where the PI sliding surface is defined as follows (Sam et al., 2004; Sam et al., 2005)

$$\sigma(t) = Cx(t) - \int_0^t (CA + CBK)x(t)dt \qquad (3)$$

Where $C \in \mathbb{R}^{mxn}$ and $K \in \mathbb{R}^{mxn}$ are constant matrices. The matrix K satisfies λ (A+BK) <0 and C is chosen so that CB is nonsingular. It is well known that if the system is able to enter the sliding mode, hence σ(t)=0. Therefore the equivalent control, U_{eq}(t) can thus be obtain by letting $\dot{\sigma}(t) = 0$ (Itkis, 1976), i.e,

$$\dot{\sigma}(t) = C\dot{x}(t) - \{CA + CBK\}x(t) = 0 \qquad (4)$$

If the matrix C is chosen such that CB is non-singular, this yields

$$u_{eq}(t) = Kx(t) - (CB)^{-1}Cf(t) \qquad (5)$$

Substituting Equation (5) into system (2) gives the equivalent dynamic equation of the system in sliding mode as

$$\dot{x}(t) = (A + BK)x(t) + \{I_n - B(CB)^{-1}C\}f(t) \quad (6)$$

Theorem 1. If $\|\tilde{F}(t)\| \leq \beta_1 = \|I_n B(CB)^{-1}C\|\beta$, the uncertain system in Eq. (6) is boundedly stable on the sliding surface $\sigma(t) = 0$

Proof. For simplicity, let

$\tilde{A} = (A + BK)$

$\tilde{F}(t) = \{I_n - B(CB)^{-1}C\}f(t)$

and rewrite (6) as

$$\dot{x}(t) = \tilde{A}x(t) + \tilde{F}(t) \quad (7)$$

Let the Lyapunov function candidate for the system is chosen as

$$V(t) = x^t(t)Px(t) \quad (8)$$

Taking the derivative of V(t) and substituting into Equation (6), gives

$$\begin{aligned}\dot{V}(t) &= x^T(t)\left[\tilde{A}^T P + P\tilde{A}\right]x(t) + \tilde{F}^T(t)Px(t) + x^T(t)P\tilde{F}(t)\\ &= -x^T(t)Qx(t) + \tilde{F}^T(t)Px(t) + x^T(t)P\tilde{F}(t) \quad (9)\end{aligned}$$

Where P is the solution of $\tilde{A}^T P + P\tilde{A} = -Q$ or a given positive definite symmetric matrix Q. It can be shown that Equation (10) can be reduced to

$$\dot{V}(t) = -\lambda_{min}(Q)\|x(t)\|^2 + 2\beta_1\|P\|\|x(t)\| \quad (10)$$