HYBRID CONTROL APPROACH BASED ON PD-SKYHOOK FOR RAILWAY VEHICLE SUSPENSION SYSTEM

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This report is submitted

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SUPERVISOR'S DECLARATION

I declare that this project report entitled "Hybrid Control Approach Based on PD-Skyhook for Railway Vehicle Suspension System" is the result of my own work except as cited in references.

Signature :..................................

Name :..................................

Date :..................................

APPROVAL

I hereby declare that I have read and checked this project report. In my opinion, this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:..................................
Name of Supervisor	:..................................
Date	:..................................

DEDICATION

To my beloved family especially my mother; Juriyani binti Chik and my father; Jazmi bin Said.

ABSTRACT

The aimed of this project is to improve the ride quality of the railway vehicle suspension system by using PD and PD-Skyhook. This project cover the simulation part results for passive suspension and semi-active suspension system of 5-DOF railway vehicle system model. The 5-DOF full car model has been developed for passive and semi-active suspension. The mathematical equation of 5-DOF railway vehicle system has been built which is consist of a vehicle body and two bogies by using MATLAB-Simulink and the simulation result have been compared based on the vehicle dynamic performance. The PD-skyhook controller or also known as hybrid controller was a combination of two different controller which are PD and Skyhook controller. The PD-Skyhook controller was built to reduce the unwanted motion produced by the vehicle system. The control algorithm for PD and PD-Skyhook were tuned by using sensitivity analysis method to obtain the precise value of PD. The results of the simulation show that the hybrid controller is able to reduce unwanted body response better than the PD controller.

ABSTRAK

Tujuan projek ini adalah untuk meningkatkan kualiti perjalanan sistem penggantungan kereta api dengan menggunakan PD dan PD-Skyhook. Projek ini meliputi hasil bahagian simulasi untuk penggantungan pasif dan sistem penggantungan separa aktif model kereta api kereta api 5-DOF. Model kereta penuh 5-DOF telah dibangunkan untuk penggantungan pasif dan separuh aktif. Persamaan matematik sistem kenderaan kereta api 5-DOF telah dibina yang terdiri daripada badan kenderaan dan dua bogie dengan menggunakan MATLAB-Simulink dan hasil simulasi telah dibandingkan berdasarkan prestasi kenderaan dinamik. Pengawal PD-Skyhook atau juga dikenali sebagai pengawal hibrid adalah gabungan dua pengawal yang berbeza yang merupakan pengawal PD dan Skyhook. Pengawal PD-Skyhook dibina untuk mengurangkan gerakan yang tidak diingini yang dihasilkan oleh sistem kenderaan. Algoritma kawalan untuk PD dan PD-Skyhook telah ditala dengan menggunakan kaedah analisis kepekaan untuk mendapatkan nilai tepat PD. Hasil simulasi menunjukkan bahawa pengawal hibrid mampu mengurangkan respons tubuh yang tidak diingini lebih baik daripada pengendalian PD.

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PID	:	Proportional Integrated Derivative
DOF	:	Degree-of-freedom
k_p	:	proportional gain
k_i	:	integral gain
k_d	:	derivative gain
m_2	:	sprung mass
m_1	:	unsprung mass
I_r	:	moment of inertia of roll motion of the sprung mass
k_1	:	stiffness of the the secondary suspension system in the lateral directions
k_2	:	stiffness of the primary suspension system in the lateral directions
k_3	:	the stiffness of the secondary suspension system in the vertical directions
b	:	half of suspension base

h_1 : length from the secondary suspension to body center

h_2 : length from the MR damper to body center

SP : Set point

PV : Process variable

K : Gain factor

P : Proportional

I : Integrated

D : Derivative

$e(t)$: error value/signal

$u(t)$: reference signal

LTI : Linear time variant

MR damper : Magneto-Rheological damper

m_c : mass of railway vehicle body

$\ddot{y}_c$: acceleration of railway vehicle body

k_f : front lateral spring stiffness

k_r : rear lateral spring stiffness

$\dot{y}_{bf}$: velocity of the front bogie

$\dot{y}_{br}$: velocity of the rear bogie

y_{bf} : displacement of the front bogie

y_{br} : displacement of the rear bogie

$\dot{y}_{cf}$: velocity of front railway vehicle body part

$\dot{y}_{cr}$: velocity of rear railway vehicle body part

y_{cf} : displacement of front railway vehicle body part

y_{cr} : displacement of rear railway vehicle body part

$m_{b,f}$: masses of front bogies

$m_{b,r}$: masses of rear bogies

$\ddot{y}_{b,f}$: accelerations of the front bogies

$\ddot{y}_{b,r}$: accelerations of the rear bogies

F_{tf} : front track lateral forces

F_{tr} : rear track lateral forces

I_r, I_y : the rolling and yawing moments of inertia

$\ddot{\theta}_c$: the rolling accelerations

$\ddot{\psi}_c$: the yawing accelerations

$k_{v,f}$ or k_2 : vertical spring stiffness of front left and right

$k_{v,r}$ or k_2 : vertical spring stiffness of rear left and right

$b_{v,f}$ or b_2 : the vertical damping coefficients of front left, front right

$b_{v,r}$ or b_2 : the vertical damping coefficients of rear left and right

$\dot{y}_{c,fl}$: velocity for front left of railway vehicle body

$\dot{y}_{c,fr}$: velocity for front right of railway vehicle body

$y_{c,fl}$: displacement for front left of railway vehicle body

$y_{c,fr}$: displacement for front right of railway vehicle body

$\dot{y}_{c,rl}$: velocity for rear left of railway vehicle body

$\dot{y}_{c,rr}$: velocity for rear right of railway vehicle body

$y_{c,rl}$: displacement for rear left of railway vehicle body

$y_{c,rr}$: displacement for rear right of railway vehicle body

$\dot{y}_{b,fl}$: velocity for front left of railway vehicle bogie

$\dot{y}_{b,fr}$: velocity for front left of railway vehicle bogie

$y_{b,fl}$: displacement for front left of railway vehicle bogie

$y_{b,fr}$: displacement for front right of railway vehicle bogie

$\dot{y}_{b,rl}$: velocity for rear left of railway vehicle bogie

$\dot{y}_{b,rr}$: velocity for rear right of railway vehicle bogie

$y_{b,rl}$: displacement for rear left of railway vehicle bogie

$y_{b,rr}$: displacement for rear right of railway vehicle bogie

l : the length of railway vehicle body

w : the width of railway vehicle body

y_c : lateral displacement of railway vehicle body

ψ_c : the yawing angles of railway vehicle body

θ_c : the rolling angles of railway vehicle body

$F_{sky,f}$: the skyhook forces of front damper

$F_{sky,r}$: the skyhook forces of rear damper

$C_{sky,f}$: the coefficients of skyhook controller of front damper

$C_{sky,r}$: the coefficients of skyhook controller of rear damper

PSM 1 : Program Sarjana Muda 1

PSM 2 : Program Sarjana Muda 2

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A PID is a proportional-integrated-derivative controller where it is common form of control loop feedback mechanism. PID controller was widely used due to acceptance applicability in process industry. In this paper, PID controller is proposed but specifically used PD and PD-skyhook controller to achieve the control objectives. The main objective of this study is to analyse the mathematical model of a railway vehicle suspension model with primary and secondary suspension elements.

The PID is used to approach the vehicle suspension control due widely used in background of many studies on vehicle suspension (Patil, Jagtap, Jadhav, Bhosale, & Kedar, 2013) and in the automobiles industrial which provide good travelling comfort to passenger (Rajagopal, Ponnusamy, & Technology, 2014). The performance of PID controller will be discussed in this study by comparing with the passive suspension, and semi-active suspension with PD and PD-skyhook controller. Based on the previous research, the skyhook controller had a good performance due ability to reduce unwanted response from the system.

Based on the Newton's Second Law, a 5 degree-of-freedom full model railway vehicle are analysed which is consist of a vehicle body and two bogies. In other hand, the 5-DOF railway vehicle model is including the lateral motion of vehicle body, yaw of the vehicle body, roll of the vehicle body, and lateral motion of each of the two bogies.

The equation of the mathematical model will used to model the dynamics of the railway system. Nowadays, modern railway vehicles used multi-body vehicle dynamic simulation as the design process. It has become a major design instrument, allowing the assessment and optimization of vehicle performance from the early stage of design process, before the prototype is built (Bruni, Vinolas, Berg, Polach, & Stichel, 2011).

According to Shin, You, Hur, and Park (2014), semi-active suspension performance is affected not only by the structure of the MR damper but also by controller design. Previous research has been stated that the popularity of PID controllers relies on the intuitive the three terms that characterize their performance which are k_p, k_i and k_d (Falconí & Ackermann, 2012). The three terms that characterized the performance will be explained detail on chapter 2 of this study.The approach of the proposed controller is to evaluate the PD and PD-skyhook control policies that provide an improvement to vehicle dynamic performance through the simulation studies. According to M. H. Harun, (2018), the paper examine the performance of the suspension control algorithm applied to the secondary suspension system of railway vehicle.

Therefore, the MATLAB-SIMULINK software is chosen as a computer simulation tool used to stimulate the vehicle dynamic behaviour and evaluate the performance of the control structure (Abdul Kadir et al., 2014). Major benefits of using software for PID design because it easy to modify and robust where it also can derive the controller designs on large batches of processes in reasonable time (Garpinger, Hägglund, & Cederqvist, 2012).

1.2 PROBLEM STATEMENT

Prior to discussion on the details of the system, it should be clear to the objectives of this study. In order to fulfil the objective which is to develop mathematical model of railway vehicles suspension model with primary and secondary suspension elements, it is needed to select the controller that need to be compare the performance of the suspension systems.

The suspension system that used is according to the external inputs that apply to the system, where the suspension can be categorized into three types which are passive, fully active and semi-active suspension systems. To model and stimulate the PD and PD-skyhook for semi-active suspension system that can improved the railway vehicles performance, the mathematical model is used to model dynamics of the railway system by using the MATLAB-SIMULINK simulation software.

The dynamic simulation is focused on the lateral body only. The lateral vibrations of the car body of railway vehicle model include the lateral and yaw motions accompanying the roll motion of the vehicle (Wang & Liao, 2009). The PD and PD-skyhook control policies that provide an improvement to vehicle dynamic performance through the simulation studies need to be evaluate based on displacement, acceleration, yaw and roll each of the systems. The vibration of suspension need to be reduced due to the input of the bogies that supply to car body of railway vehicle model is complex. This study only focused on secondary suspension. Any motion come from bogies and supply to the body, the secondary suspension can serve up the unwanted motion before it is transfer to the car body of railway vehicle model which result the better ride comfort.