Modified skyhook control to improve ride quality of railway vehicle

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Keywords: modified skyhook control; secondary suspension; railway vehicle; semi-active suspension

ABSTRACT – The aim of this paper is to study the performance of secondary suspension system of railway vehicle with passive and semi-active systems. The governing equation of five degrees of freedom (5-DOF) railway vehicle model which includes a vehicle body, two sets of bogie are derived and formulated. Two control strategies were used for secondary suspension namely skyhook and modified skyhook controllers. The results of passive and semi-active controls of are compared in terms of railway vehicle body acceleration, body displacement and body roll angle. It can also be noted that the modification of skyhook control is able to improve the performance of ride quality effectively.

1. INTRODUCTION

Passive system provides low performance and less costly when compare with semi-active and active systems. Both semi-active and active suspensions provide good performance especially active system, but semi-active system is also able to perform as good as active system if it is well designed with less cost than active system [1, 2]. Generally, in railway vehicle industry, research and development of active suspension system has recently increased compared to passive and semi-active system, since it offers high control performance over a wide frequency range [3]. Although an active suspension system is capable of keeping the railway vehicle body in the very best condition, it has some limitation in terms of cost since it requires high power and sophisticated control implementation.

The previous study on semi-active and active control made full use of the advantages and has an ability to solve the vibration problems in railway vehicle suspension. Much successful theoretical work on semi-active and active control for body vibration of railway vehicle has been carried out in China [4] and Japan [5]. However, there are many challenges in research and development of semi-active suspension system. The practical application has been limited because of the existence of system error, random error and also an external disturbance in all tests and control process [4]. This paper examine the performance of the suspension control algorithm applied to the secondary suspension system of railway vehicle. In this study, two control algorithms namely skyhook and modified skyhook controllers are evaluated to be as a semi-active suspension control for railway vehicle.

2. SEMI-ACTIVE RAILWAY VEHICLE SUSPENSION

2.1 5-DOF railway vehicle model

A 5-DOF full model of railway vehicle consists of a vehicle body and two bogies are derived based on the Newton's Second Law which consists of yaw, roll of vehicle body, and lateral motion of vehicle body and each two bogies. The complete dynamical equations of the railway vehicle model will be used to model the dynamics of the railway system in MATLAB-Simulink software.

2.2 Control Strategies

In this study, the controllers that have been used as a system controller are skyhook and modified skyhook controller. The structures of these two controllers are presented in this section.

i. Skyhook control

The ideal skyhook controller is assumed to be connected from the railway vehicle body to a point considered in the sky. The equations of skyhook controller are governed by:

$$F_{sky,f} = C_{sky,f}\left(\dot{y}_{cf} + \tfrac{l}{2}\dot{\psi}_c\right) \quad (1)$$

$$F_{sky,r} = C_{sky,r}\left(\dot{y}_{cr} - \tfrac{l}{2}\dot{\psi}_c\right) \quad (2)$$

where $F_{sky,f}$ and $F_{sky,r}$ are the skyhook forces of front and rear damper, $C_{sky,f}$ and $C_{sky,r}$ are the coefficients of skyhook controller of front and rear damper, and $\dot{\psi}_c$ is the yawing rate of railway vehicle body.

ii. Modified skyhook control

The general idea of modified skyhook controller has been developed is to improve the existing skyhook controller by emulating the skyhook damper with semi-active suspension system. The governing equations of modified skyhook controller are presented by

$$F_{msky,f} = \left(C_{sky,f}.\dot{y}_{cf}\right) + b_f\left(\dot{y}_{cf} + \dot{y}_{bf}\right) \quad (3)$$

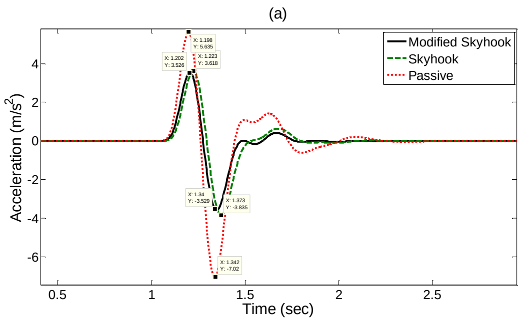
$$F_{msky,r} = \left(C_{sky,r}.\dot{y}_{cr}\right) + b_r\left(\dot{y}_{cr} - \dot{y}_{br}\right) \quad (4)$$

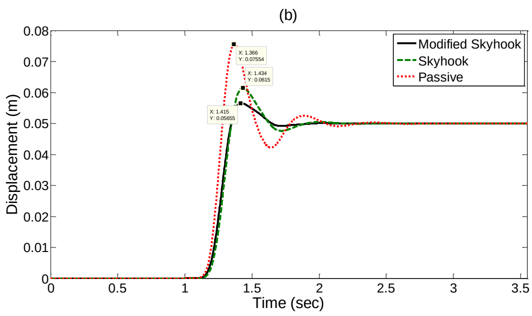
where $F_{msky,f}$ and $F_{msky,r}$ are the modified skyhook damping forces of front and rear respectively. The control action of modified skyhook is applied when the control force is opposite direction of suspension relative velocity. The damping constant for front and rear skyhook $C_{sky,f}$ and $C_{sky,r}$ are determined with the following rule:

$$C_{sky} = \begin{cases} C_{sky,\max} & if \quad V_{body} \times V_{rel} \geq 0 \\ C_{sky,\min} & if \quad V_{body} \times V_{rel} < 0 \end{cases} \qquad (5)$$

3. RESULTS AND DISCUSSION

Figure 3.1(a) to 3.1(c) show the responses of railway vehicle body due to the step input. From the graph, the peak-to-peak value of acceleration for the passive system is 12.66 m/s^2, while for the system with skyhook and modified skyhook controller, smaller peak-to-peak values of the accelerations are 7.45 m/s^2 and 7.06 m/s^2 respectively. In terms of body displacement, the percentage of overshoot of unwanted displacement of railway vehicle body has been reduced by almost 23 % (0.0615 m to 0.05 m) when using modified skyhook controller, and 13.1 % (0.078 m to 0.061 m) improvement when using skyhook controller. For roll angle response, the peak to peak values for passive, skyhook and modified skyhook controllers are 11×10^{-3}, 6.8×10^{-3} and 6.2×10^{-3} respectively.





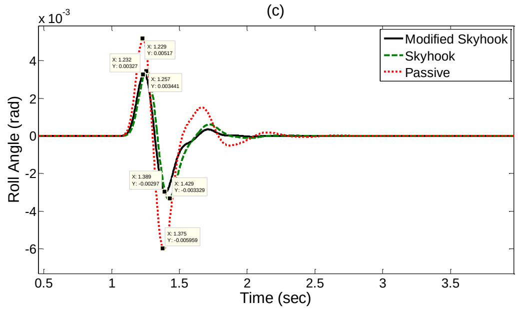


Figure 3.1 Railway vehicle body responses for step input disturbance (a) Body acceleration (b) body displacement (c) Body roll angle

4. SUMMARY

Semi-active suspension in railway vehicle suspension has been evaluated through a computer simulation using a full car railway vehicle with 5-DOF. From the simulation results, it shows that the semi-active suspension system of railway vehicle with both modified skyhook and skyhook controllers improve ride quality of railway vehicle.

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