HYBRID FRACTIONAL MODIFIED SKYHOOK CONTROLLER OPTIMIZED BY PARTICLE SWARM OPTIMIZATION FOR RAILWAY SECONDARY LATERAL SUSPENSION

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DEDICATION

This thesis is specifically for both my parents, who have taught and educated me on the meaning of patience in seeking knowledge, and for my beloved wife and kids, who always give me positive vibes.

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ABSTRACT

The suspension system is one of the mechanical systems in railway vehicles that offers greater ride quality to enhance ride comfort for passengers. However, the existing suspension system in a railway vehicle has a limitation in absorbing vibratory motion due to the lateral track irregularity. The unwanted vibratory motion reduces the ride performance of the railway vehicle system, thus leading to discomfort for railway vehicle passengers when excessive track interference occurs. Following this, it is essential to minimize unwanted vibratory motion so that the level of passenger comfort can be improved. The overall goal of the study is to enhance the railway vehicle ride performance by implementing a semi-active secondary suspension system via magneto-rheological (MR) fluid damper. Initially, a seventeen degrees of freedom (DOF) railway vehicle simulation model was developed which included the motions of lateral body acceleration ($\ddot{y}_c$), yaw angle (ψ_c, ψ_{b1}, ψ_{b2}) and roll angle of vehicle body and two bogies, (θ_c, θ_{b1}, θ_{b2}) as well as lateral acceleration ($\ddot{y}_{w1}$, $\ddot{y}_{w2}$, $\ddot{y}_{w3}$, $\ddot{y}_{w4}$) and roll angle (θ_{w1}, θ_{w2}, θ_{w3}, θ_{w4}) of four wheelsets. The effects of primary and secondary suspension elements were analysed using MATLAB/Simulink software and the result identified that the lateral damper for secondary suspension improved the railway vehicle body's comfort level more than others by around 69.6% based on $\ddot{y}_c$ of the vehicle body. The study was then continued with the development of a small-scale railway vehicle test rig. The parameters for the test rig were obtained via dimensionless analysis study known as Pascal Modified method. Next, the experimental setup, calibration, modelling, and validation works on MR damper had been performed, and the force tracking control performance was assessed by using step, sinewave and saw-tooth inputs. After the small-scale railway vehicle test rig and MR damper models were validated, the performance of the proposed control strategy, specifically Body-based Modified Skyhook (BD-MS), Bogie-based Modified Skyhook (BG-MS), and Hybrid Body-based Bogie-based Modified Skyhook (HBB-MS) controllers optimized by Particle Swarm Optimization (PSO) were also examined against the passive system. The simulation results showed that the performances of BD-MS, BG-MS and HBB-MS controllers respectively improved until 13.9%, 61.6%, 85.1% reduction of $\ddot{y}_c$, 17.1%, 26.4%, 69.9% reduction of θ_c, and 18.5%, 29.6%, 58% for reduction of ψ_c. Lastly, the suspension system was further controlled by using a Hybrid Body-based Bogie-Based Fractional Modified Skyhook (HBB-FMS) controller to study the potential benefit of fractional gain in improving the railway vehicle body responses. The findings from the simulation work showed that the HBB-FMS controller provides better performance of about 43.5% in $\ddot{y}_c$, 31% in θ_c, and 44.9% in ψ_c against the HBB-MS controller. Therefore, it can be concluded that the semi-active suspension system with HBB-FMS controller was found effective in enhancing the ride performance of the railway vehicle by mitigating the unwanted vibratory motion on the railway vehicle body due to lateral track irregularities.

ABSTRAK

Sistem gantungan adalah salah satu sistem mekanikal dalam kenderaan keretapi yang menawarkan kualiti perjalanan yang lebih baik untuk meningkatkan keselesaan perjalanan kepada penumpang. Walau bagaimanapun, sistem gantungan sedia ada dalam kenderaan keretapi mempunyai had dalam menyerap gerakan getaran disebabkan oleh ketidakteraturan landasan sisi. Pergerakan getaran yang tidak diingini mengurangkan prestasi tunggangan sistem kenderaan keretapi, sekali gus membawa kepada ketidakselesaan kepada penumpang kenderaan keretapi apabila gangguan trek yang berlebihan berlaku. Disebabkan ini, adalah penting untuk meminimumkan gerakan getaran yang tidak diingini supaya tahap keselesaan penumpang dapat dipertingkatkan. Matlamat keseluruhan kajian adalah untuk meningkatkan prestasi tunggangan kenderaan keretapi dengan melaksanakan sistem gantungan sekunder separa aktif melalui peredam bendalir *magneto-rheological* (MR). Pada mulanya, model simulasi kenderaan keretapi dengan tujuh belas darjah kebebasan (DOF) telah dibangunkan berdasarkan undang-undang kedua Newton yang merangkumi gerakan pecutan badan sisi ($\ddot{y}_c$), sudut rewang (ψ_c, ψ_{b1}, ψ_{b2}) dan sudut guling bagi badan kenderaan dan dua bogi (θ_c, θ_{b1}, θ_{b2}), serta pecutan badan sisi ($\ddot{y}_{w1}$, $\ddot{y}_{w2}$, $\ddot{y}_{w3}$, $\ddot{y}_{w4}$) dan sudut guling (θ_{w1}, θ_{w2}, θ_{w3}, θ_{w4}) bagi empat set roda. Kesan unsur suspensi primer dan sekunder dianalisis menggunakan perisian MATLAB/Simulink dan keputusannya mengenal pasti peredam sisi untuk suspensi sekunder meningkatkan tahap keselesaan badan kenderaan keretapi lebih daripada yang lain sekitar 69.6% berdasarkan $\ddot{y}_c$ bagi badan keretapi. Kajian itu kemudiannya diteruskan dengan pembangunan pelantar ujian kenderaan keretapi berskala kecil. Parameter bagi pelantar ujian diperolehi melalui kajian analisis tanpa dimensi yang dikenali sebagai kaedah Modifikasi Pascal. Kemudian, model simulasi telah disahkan menggunakan data eksperimen dari pelantar ujian. Seterusnya, kerja-kerja persediaan eksperimen, penentukuran, pemodelan dan pengesahan pada peredam MR telah dilakukan, dan prestasi pengawal pengesanan daya dinilai. Selepas pelantar ujian kenderaan keretapi berskala kecil dan model peredam MR disahkan, prestasi strategi kawalan yang dicadangkan, khususnya Modifikasi Skyhook Berasaskan-Badan (BD-MS), Modifikasi Skyhook Berasaskan-Bogi (BG-MS) dan Pengawal Modifikasi Skyhook Hibrid berasaskan Badan-Bogi (HBB-MS) dioptimumkan oleh Pengoptimuman Kawanan Zarah (PSO) juga telah diperiksa terhadap sistem pasif. Keputusan menunjukkan bahawa pengawal BD-MS, BG-MS dan HBB-MS masing-masing bertambah baik sehingga 13.9%, 61.6%, 85.1% pengurangan pada $\ddot{y}_c$, 17.1%, 26.4%, 69.9% pengurangan pada θ_c, dan 18.5%, 29.6%, 58% pengurangan pada ψ_c. Akhir sekali, sistem penggantungan dikawal lagi dengan menggunakan pengawal Pecahan Modifikasi Skyhook Hibrid berasaskan Badan-Bogi (HBB-FMS) untuk mengkaji potensi kelebihan pecahan gandaan dalam menambah baik tindak balas badan kenderaan keretapi disebabkan pelbagai ketidakteraturan keadaan penyelewengan trek. Hasil penemuan menunjukkan bahawa pengawal HBB-FMS boleh memberikan prestasi yang lebih baik kira-kira 43.5% untuk $\ddot{y}_c$, 31% untuk θ_c, dan 44.9% untuk ψ_c terhadap pengawal HBB-MS. Maka, dapat disimpulkan bahawa sistem gantungan separa aktif dengan pengawal HBB-FMS didapati berkesan dalam meningkatkan prestasi tunggangan kenderaan keretapi dengan mengurangkan gerakan getaran yang tidak diingini yang dihasilkan pada badan kenderaan keretapi disebabkan oleh penyelewengan trek sisi.

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LIST OF ABBREVIATIONS

ADAMS	-	Automated Dynamic Analysis of Mechanical System
BD-MS	-	Body-Based Modified Skyhook
BG-MS	-	Bogie-Based Modified Skyhook
DOF	-	Degree of Freedom
FLC	-	Fuzzy Logic Controller
FTC	-	Force Tracking Control
GSA	-	Gravitational Search Algorithm
HBB-MS	-	Hybrid Body-Based Bogie-Based Modified Skyhook
HBB-FMS	-	Hybrid Body-Based Bogie-Based Fractional Modified Skyhook
ISO	-	International Standard Organization
KSR	-	Korean Standard of Ride Evaluation
LVDT	-	Linear Variable Differential Transformer
MATLAB	-	Matrix Laboratory
MBS	-	Multi-Body System
MR	-	Magnetorheological
PID	-	Proportional, Integral, and Derivative
PSD	-	Power Spectral Density
PSO	-	Particle Swarm Optimization
RMS	-	Root Mean Square

LIST OF SYMBOLS

a	-	Experimental coefficient of MR damper
B	-	Feedback gain
b	-	Wheelsets spacing
$C_{bd\_msky,f}$	-	Damping constant of BD-MS controller of front body
$C_{bd\_msky,r}$	-	Damping constant of BD-MS controller of rear body
$C_{bg\_msky,f}$	-	Damping constant of BG-MS controller of front body
$C_{bg\_msky,r}$	-	Damping constant of BG-MS controller of rear body
c_g	-	Gravitational coefficient
c_{1y}	-	Primary lateral damping coefficient
c_{2y}	-	Secondary lateral damping coefficient
F_{bd_msky}	-	Target force of MR damper calculated using BD-MS controller
F_{bg_msky}	-	Target force of MR damper calculated using BG-MS controller
F_d	-	Desired MR damper force
$F_{hmsky,f}$	-	Target force of MR damper calculated using HBB-MS of front body
$F_{hmsky,r}$	-	Target force of MR damper calculated using HBB-MS of rear body
F_{MR}	-	MR damper force
f_{11}	-	Longitudinal creep force coefficient
f_{22}	-	Lateral creep force coefficient
F_{gi}	-	Lateral restoring force
F_{pxil}	-	Suspension force of the left primary longitudinal suspension
F_{pxir}	-	Suspension force of the right primary longitudinal suspension
F_{pyil}	-	Suspension force of the left primary lateral suspension
F_{pyir}	-	Suspension force of the right primary lateral suspension
F_{pzil}	-	Suspension force of the left primary vertical suspension
F_{pzir}	-	Suspension force of the right primary vertical suspension

F_{sxil}	-	Suspension force of the left secondary longitudinal suspension
F_{sxir}	-	Suspension force of the right secondary longitudinal suspension
F_{syil}	-	Suspension force of the left secondary lateral suspension
F_{syir}	-	Suspension force of the right secondary lateral suspension
F_{szil}	-	Suspension force of the left secondary vertical suspension
F_{szir}	-	Suspension force of the right secondary vertical suspension
F_{yil}	-	Creep moment induced by lateral creep force of left wheelset
F_{yir}	-	Creep moment induced by lateral creep force of right wheelset
G	-	Proportional Gain
h_1	-	height from centre of body mass to the upper line of second spring
h_2	-	height from centre of body mass to central lateral damper
h_3	-	height from the upper line of second spring to centre of sprung mass of bogie
h_4	-	height from centre of sprung mass of bogie to the centre line of wheelsets
h_5	-	height from centre of sprung mass of bogie to central lateral damper
i	-	Subscript of the wheelsets at front bogie
I	-	Current
$I_{b\psi}$	-	Bogie yaw inertia
$I_{b\theta}$	-	Bogie roll inertia
$I_{w\psi}$	-	Wheelset yaw inertia
j	-	Subscript of the wheelsets at rear bogie
k_{1y}	-	Primary lateral spring stiffness
k_{2y}	-	Secondary lateral spring stiffness
L	-	Distance between the central line of the bogie and vehicle body
L_1	-	Half distance between two-wheel of each bogie
m_b	-	Mass of the bogie
m_c	-	Mass of the body
M_{gi}	-	Yaw moments induced by gravity force for each wheelsets

m_w	-	Mass of the wheelsets
M_{zi}	-	Creep moments induced by the longitudinal creep forces
N	-	Scaling ratio
r_o	-	Wheelset radius
v	-	Velocity of railway vehicle
y_b	-	Bogie lateral displacement
$\dot{y}_b$	-	Bogie lateral velocity
$\ddot{y}_b$	-	Bogie lateral acceleration
y_c	-	Body lateral displacement
$\dot{y}_c$	-	Body lateral velocity
$\ddot{y}_c$	-	Body lateral acceleration
y_w	-	Wheelsets lateral displacement
$\dot{y}_w$	-	Wheelsets lateral velocity
$\ddot{y}_w$	-	Wheelsets lateral acceleration
α	-	Passive to BD-MS ratio
β	-	Passive to BG-MS ratio
δ	-	Fractional gain of BD-MS controller
ψ_b	-	Yaw angle of the bogie
$\dot{\psi}_b$	-	Yaw rate of the bogie
$\ddot{\psi}_b$	-	Yaw acceleration of the bogie
ψ_c	-	Yaw angle of the body
$\dot{\psi}_c$	-	Yaw rate of the body
$\ddot{\psi}_c$	-	Yaw acceleration of the body
ψ_w	-	Yaw angle of the wheelsets
$\dot{\psi}_w$	-	Yaw rate of the wheelsets
$\ddot{\psi}_w$	-	Yaw acceleration of the wheelsets
θ_b	-	Roll angle of the bogie
$\dot{\theta}_b$	-	Roll rate of the bogie
$\ddot{\theta}_b$	-	Roll acceleration of the bogie

θ_c	-	Roll angle of the vehicle body
$\dot{\theta}_c$	-	Roll rate of the body
$\ddot{\theta}_c$	-	Roll acceleration of the body
ρ	-	Horizontal track irregularity
λ_s	-	Slip ratio of wheelsets
λ	-	Fractional gain of BG-MS controller
ξ	-	Lateral irregularity of the track under wheelsets
ω	-	Axle mass
φ_l	-	Length factor
φ_{full}	-	Characteristic length of full-scale
φ_{scaled}	-	Characteristic length of small-scale
μ	-	BD-MS to BG-MS ratio

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CHAPTER 1

INTRODUCTION

1.1 Research Overview

In a big city such as Kuala Lumpur, the railway vehicle transportation system is one of the transport systems of choice by the urban community as a more effective public transport than other public vehicles. The main contribution factor is the exceptional vehicle service experiences, which are free from traffic jams, comfortable in travelling, fast, and punctual that enable the entire passenger to manage their itinerary effectively. Concerning this situation, railway transportation industries and companies are putting remarkable effort in fulfilling their passengers' satisfaction with the provided services in terms of timeliness, operational efficiency, safety, and passenger comfort levels.

The suspension system in railway vehicles is dissimilar from the automotive vehicle suspension system especially in terms of suspension layout. It has two levels of suspension system known as primary and secondary suspension systems. The primary and secondary suspensions in railway vehicles have their own responsibility. The primary suspension that connects the railway vehicle bogie with the wheelset serves as a system that controls the stability and performance of the bogie, especially during curving. Meanwhile, the secondary suspension system works to maintain the level of ride quality resulting from vibrations caused by the track irregularity.[1].

The suspension system for railway vehicle can be passive, semi-active, or fully active. Current suspension technology in railway vehicles, especially in Malaysia, are mostly using passive or conventional suspension system configuration. However, this type of suspension has limitations to cancel out unwanted motions, especially when the railway vehicle experiences disturbance from the track, which beyond the capability of passive suspension. This conventional technology needs to be improved with the new system technology that can adapt to various ranges of speed and track disturbances, and the system technology that can overcome this problem is controllable or adjustable suspension technology. Therefore, the study on the semi-active system is very necessary to solve the problem of the passive system in maintaining the comfort level of train passengers caused by track irregularity [2].

According to Hudha [3], controllable suspension technology in railway vehicles can be divided into two general categories. The first is to increase running stability and wheelset guidance, and the second is to improve the ride quality of the railway vehicle. The bogie stability and wheelset guidance performance can be improved by focusing on the primary suspension system modification, while the ride quality has the potential to be improved by modifying the secondary suspension system. This advanced suspension technology can be applied to the primary and secondary suspension system simultaneously, but it requires a lot of time to work on it, and high operational costs. However, it can still be applied separately, either on the primary or secondary suspense system, depending on the purpose and objective. In this study, emphasis will be given to the secondary suspension system which uses an electronic control system on the lateral suspension system located between the vehicle body and bogie that covers the yawing and rolling modes as well as all the responses in a lateral direction.

The main objective of this study is to determine the performance of railway vehicle suspension featuring a semi-active magnetorheological (MR) damper. The control strategy for the lateral movement was measured to improve ride quality due to the track irregularities. To study the lateral vibration of the railway vehicle, a small-scale railway vehicle test rig had been developed. A 17 DOF of the suspension model was developed following the test rig design. The semi-active dampers were located at both the front and rear of secondary suspensions that connects the bogie to the body of the railway vehicle.

1.2 Problem Statement

Many investigations have been done by researchers and engineers globally, on suspension system of the railway vehicle. The ride quality is a term used as a performance evaluation of railway vehicle suspension and is usually interpreted as the capability of the suspension system to reject unwanted motions or maintain within the range of human comfort. The ride quality of a railway vehicle depends on vertical and lateral motions (displacement, acceleration, and rate of change of acceleration). Generally, railway companies in developing countries such as Malaysia are still using conventional suspension system in their railway vehicle system. From a technical perspective, the conventional suspension system in railway vehicle is designed to achieve certain conditions, which require a compromise between the ride comfort and stability. To achieve a good compromise between these two performances, the purpose of the main elements of a suspension system which are the spring and damper need to be understood. Technically their characteristics are fixed and only valid to work in a certain condition. A soft suspension is needed when the goals are towards the ride comfort. Meanwhile, a hard suspension setting will be selected for better ride stability. Unfortunately, these two goals cannot be realized through a conventional suspension system since it cannot provide both ride quality and stability simultaneously. Due to these conflicting demands, an ideal suspension system should be designed to capable of fulfilling these two requirements simultaneously. Thus, the implementation of an advanced suspension system is well suited for this purpose.

Another method that can be considered for better ride quality performance is by maintaining the track condition from any irregularities. However, the cost of track maintenance is expensive, and it also requires a longer time to be fixed. The basic characteristics of the wheel-rail interface must be accurately managed although it is difficult to achieve and keep it under control. The main task of an engineer is to ensure that ride quality can be improved or at least maintain at an acceptable level even though the track conditions are poor. Due to this constraint, the idea of solving the problem is by focusing on the suspension system that can keep the vehicle body at an acceptable level with a significantly lower cost. The controllable and adjustable suspensions have been widely studied experimentally [4-8] and theoretically [9-13] for railway vehicles due to the limitation of conventional suspension in dissipating energy that is transferred from the wheelset to the vehicle body. However, the passive, semi-active and active suspension has its advantages and disadvantages. Although the passive system provides low performance, but in terms of maintenance costs are less costly when compared to controllable suspension. Although both semi-active and active suspensions can provide better performance than passive system, the cost of maintenance, especially the active system makes it difficult for some railway companies to consider this. However, with the advantages of a semi-active system that can function as good as the active system, it is preferable since it is cheaper than an active system.

Researches on semi-active suspension systems had been carried out by [3, 14-17] and active systems by [18, 19] for body vibration control of the railways. Though, many challenges must be considered especially in the research and development of the semi-active system. Practical applications are limited because of the frequent occurrences of a system error, random error and also external disturbances [14]. In the area of heavy vehicles, a limited amount of research had been done, which resulting in no commercially available controllable damper that is suitable for railway vehicle suspension. To answer this problem, a scale model of a railway vehicle with a semi-active secondary suspension system was developed for the experimental study.

1.3 Research Objectives

The general objective of this study is to improve the ride quality of railway vehicle suspension by developing controllers for a secondary suspension system to control the railway vehicle body response. The specific objectives of this research are stated as follows:

(a) To develop and validate the mathematical model of railway vehicle with the full-scale validated model.

(b) To explore the effects of secondary lateral suspension on the ride performance of the railway vehicle.

(c) To validate the small-scale railway vehicle lateral model with the small-scale railway vehicle test rig.

(d) To evaluate the performance of the optimised controller using particle swarm optimization in rejecting unwanted railway vehicle body motions through computer simulation work.

1.4 Research Scopes

The scopes of the study are defined as follow:

(a) The railway vehicle model was developed with the intended to study the lateral movement of the vehicle body, and not consider the movement in the vertical direction.

(b) The small-scale railway vehicle test rig was developed and limited for the testing procedure in the laboratory environment.

(c) Only the ride quality analysis is performed, and the railway vehicle ride stability is neglected.

(d) The simulation work was carried out by using both railway vehicle validated model, and MR damper validated model. The response of the vehicle body was evaluated in terms of vehicle body lateral acceleration, roll angle and yaw angle.

(e) Modelling of the semi-active controller for secondary lateral suspension system.

(f) Controller performances are evaluated only using selected parameter scaling method

(g) The response of the passive and semi-active suspension system are compared in the time response only.

(h) The simulation model of railway vehicle is modelled using MATLAB/Simulink software.

1.5 Research Contributions

In general, the research study has contributed to the improvement of the railway vehicle dynamic behaviours utilizing the semi-active system located on the secondary lateral suspension in a railway vehicle. This work will significantly give advantages to the railway vehicle industry where the company of railway vehicles can use the output of this study for ride quality improvement. The major contributions of the study are summarized as follows:

(a) A parametric study in analysing the influence of primary and secondary suspension system parameters on the railway vehicle dynamic behaviours.

(b) A parameter scaling strategy was conducted through numerical analysis to gain the parameter values of the small-scale model from the parameters of a full-scale railway vehicle model.

(c) Developing a novel small-scale railway vehicle test rig and hence allowing for mathematical model validation.

(d) A new controller was proposed in the railway vehicle simulation model with the semi-active suspension system.

1.6 Structure and Layout of the Thesis

The thesis consists of seven chapters, and the chapter is structured as follows: Chapter 1 explains in detail an overview of the railway vehicle suspension system. It is followed by the problem statement, objectives, scopes of study, and summary of research contribution. The outline of the thesis is also described in this chapter.

Chapter 2 describes the literature review on previous work and the research development accomplished by other researchers and academicians on the railway vehicle suspension system and MR damper. It concludes the general information of conventional and advanced railway vehicle suspensions system and research development in railway vehicle suspension. A review of recent articles related to the control strategies is also presented. Furthermore, the research gap of the study is also featured.

Chapter 3 presents the research methodology used throughout the study to develop the semi-active suspension to improve the ride quality of railway vehicles. The study begins with the development of a 17 DOF railway vehicle full car. The modelling assumptions and parameter scaling strategy are presented. The development of a small-scale railway vehicle test rig used to validate the model is also described. The experimental setup of the test rig is also presented for validation purposes. The experimental set up for MR damper testing and its modelling are also described.

Chapter 4 covers the mathematical model validation and analysis of the railway vehicle model with full-scale parameters. In the beginning, the model assumption is provided to analyse the performance of railway vehicle dynamic behaviours. The model is compared with the selected validated model found in the literature for initial evaluation before further analysis is done. The parametric study of suspension parameters is also described to study the influence of suspension elements on railway vehicle dynamics. Finally, the results of model verification and analysis on the effect of primary and secondary suspensions systems on the ride performance of the railway vehicle body are presented.

Chapter 5 elaborates the study that being conducted on a small-scale model in gaining the data and tracking the behaviour of larger railway vehicle models as close as possible. This chapter also describes model validation based on the small-scale railway vehicle test rig, which is typically a reduced-size version of the full-scale model. Then, the experimental works are continued with the MR damper model where the behaviour of the MR damper was investigated. The mathematical modelling and force tracking control of the MR damper model were also discussed.

Chapter 6 presents the controllers development of a railway vehicle suspension system featuring the MR damper. The proposed controller for the semi-active suspension system are Body-based Modified Skyhook (BD-MS), Bogie-based Modified Skyhook (BG-MS) and Hybrid Body-based Bogie-based Modified Skyhook (HBB-MS) controllers. The performances of the railway vehicle body responses are evaluated by compare the semi-active system with the responses of the passive suspension system. The railway vehicle model is tested with several track irregularity input namely the sinewave, periodical, and random track inputs. Chapter 6 also presents the possible improvement of the HBB-MS controller where the fractional gain is added into the BG-MS and BD-MS controllers. It transforms the linear hybrid to the non-linear controller and is named as Hybrid Body-based Bogie-based Fractional Modified Skyhook (HBB-FMS) controller. For the performance evaluation, the results obtained from the HBB-FMS controller are analysed and compared with the passive and HBB-MS controller.

Finally, in Chapter 7, all the results are summarized and concluded, and some recommendations for future works are proposed.

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