MODELLING AN AIR SPRING SUSPENSION FOR SECONDARY RAILWAY VEHICLE SUSPENSION SYSTEM

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This report is submitted
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DECLARATION

I declare that this thesis entitled “MODELLING AN AIR SPRING SUSPENSION FOR SECONDARY RAILWAY VEHICLE SUSPENSION SYSTEM” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have checked this report entitled “MODELLING AN AIR SPRING SUSPENSION FOR SECONDARY RAILWAY VEHICLE SUSPENSION SYSTEM” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechanical Engineering with Honors.

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

DEDICATION

This thesis is dedicated to my parents especially those who have sacrificed a lot for my studies at UTeM. They are one of my toughest inspirations in making this study this much with my hardest effort. They have been a pillar for me in completing this PSM project. They have helped me in financial and provide me tools in completing this final draft.

ABSTRACT

Railway vehicles have evolved significantly over the previous century, but the suspension mechanism has remained relatively the same. This outdated system needs some testing and validation to improve the working principle of railways vehicles. In this study, simulation software named MATLAB Simulink is used to simulate the railway suspension system. This study presents a secondary suspension system for railway vehicles. The basic concepts of the railway vehicle suspension system and its vibration characteristics were analysed and investigated. The study has compared two different models namely Nishimura and Conventional model. Both models were developed based on Newton's second law and were simulated in MATLAB simulation software. To simulate the suspension models, sets of parameters have been used for spring and damper. The simulation outputs were evaluated according to the vibration characteristics of the railway vehicle body. This simulation results show that Nishimura is selected as a better model if compared to Conventional and it has been chosen for further findings. It is because Nishimura has lower vibration amplitude over acceleration and displacement compared to the Conventional model. Nishimura model is then used to analyse the vibration amplitude if certain parameters were manipulated.

ABSTRAK

Kenderaan kereta api telah berkembang dengan ketara sepanjang abad sebelumnya, tetapi mekanisme penggantungannya tetap sama. Sistem usang ini memerlukan beberapa pengujian dan pengesahan untuk meningkatkan prinsip kerja kenderaan kereta api. Dalam kajian ini, perisian simulasi bernama MATLAB Simulink digunakan untuk mensimulasikan sistem suspensi keretapi. Makalah ini mengemukakan sistem penggantungan sekunder untuk kenderaan kereta api. Konsep asas sistem suspensi kenderaan kereta api dan ciri getarannya dianalisis dan diselidiki. Kajian ini membandingkan dua model berbeza iaitu model Nishimura dan model Simple. Kedua-dua model ini dikembangkan berdasarkan undang-undang kedua Newton dan disimulasikan dalam perisian simulasi MATLAB. Untuk mensimulasikan model suspensi, set parameter telah digunakan untuk spring dan peredam. Hasil simulasi dinilai mengikut ciri getaran badan kenderaan kereta api. Hasil simulasi ini menunjukkan bahawa Nishimura dipilih sebagai model yang lebih baik jika dibandingkan dengan Simple dan telah dipilih untuk kajian selanjutnya. Ini kerana Nishimura mempunyai amplitud getaran lebih rendah daripada pecutan dan sesaran dibandingkan dengan model Simple. Model Nishimura kemudian digunakan untuk menganalisis amplitud getaran jika parameter tertentu dimanipulasi.

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b_1 = Secondary damping coefficient

b_2 = Primary damping coefficient

F = Force

m_1 = Body mass

m_1 = Bogie mass

m_{mp} = Air spring mass

K_1 = Air spring stiffness

K_2 = Secondary reservoir stiffness

K_3 = Primary spring stiffness

K_4 = Air spring change of area stiffness

X = Displacement

$\dot{X}$ = First derivatives of X

$\ddot{X}$ = Second derivatives of X

CHAPTER 1

INTRODUCTION

1.1 Background

Over a few years ago, railway vehicles have improved more in a way of technologies, along with conventional mechanical systems. More and more electronics, sensors and controls are being used to suit and keep going for the modern high-speed demands, improved driving efficiency and tighter safety requirements. To enhance the dynamics of the railway vehicle, only a few methods of active control have been implemented. The active suspension system can be classified into active primary suspension and active secondary suspension.

Air spring is one of the secondary suspension system components which act as load-carrying portion used on railway vehicle especially. Air springs have been used in heavy-duty vehicle suspension systems, where they have been able to provide utility by taking advantage of the compressed air needed for vehicle braking systems. One of the mechanical advantages of air suspension is by being able to adjust the air pressure within the spring, which changes the spring rate, and thus the consistency of the ride.

The air spring is one of the important suspension parts that connects the body and the bogie of the railway vehicle. The key task is to reduce the acceleration of the railway vehicle to a lower frequency range, about 1 Hz (Orvnas, 2010). In railway vehicles, the secondary suspension also helps to attenuate vehicle movements from track vibrations when moving static and quasi-static loads with constrained deflections from the car-body to the bogie.

1.2 Problem Statement

The crucial part component in the railway vehicle system is a body to the bogie. Here when the train runs in higher acceleration, the train body and the bogie part will have a certain consideration that will cause some bouncing effects on the train. The train will have some shaking effect as well and this will affect the train in danger.

Other than that, once the train having the bouncing effect or when the train runs on a rusty railway track, it will reduce the passengers comfort level. The passengers will feel uncomfortable and they will be in a desperate situation.

Furthermore, mostly railway vehicles have higher body vibrations that affect passengers' comfort. This is will affect passenger safety when there is a crowd of passengers on the specific train. To that, an improvement needed to be implemented such as air spring model as a secondary suspension system.

1.3 Objectives

The objectives of this project are:

1) To model an air spring suspension system as a suspension system of the train.
2) To study which types of air spring model gives the best suspension system in terms of railway vehicle body performance.
3) To analyse the effect of air spring parameters on the railway vehicle body performance.

1.4 Scope of Project

The scopes of this project are:

1) To study the structure of the conventional air spring model and Nishimura air spring model for the railway suspension system.

2) To identify the corresponding vertical quarter car model for the railway suspension system.
3) To study the secondary suspension system for railway vehicles.
4) To analyze, plot data and read the waveform data using MATLAB only.

1.5 Thesis Outline

The report is organized the following way.

Chapter 1 introduces the background of the suspension system in railway vehicle. It also describes the problem statements and objectives of this study. This chapter acts as a starting pack for this study.

Chapter 2 introduces the history and the function of air springs to the reader. Simple concepts of air spring are discovered in this chapter and it is to make it simpler and more informative to read more. The topic is based on a review of the literature study.

Chapter 3 describes the methodology to model an air spring and choose the suitable air spring to be used. The content is about a few types of existing air spring models. The parameters and values are also briefly covered. This chapter also gives an analysis done using MATLAB simulation.

Chapter 4 discussed the results and discussion part of both Conventional and Nishimura air spring models obtained from the simulation work. The results are tabulated in graphs and then discussed accordingly.

Chapter 5 concluded the overall works throughout this research. It also discussed the recommendation part for future works for railway vehicle improvements.

1.6 Summary

The outcome of this chapter is to study and understand the background of railway vehicles. This chapter also explained the problems faced by railway vehicles and the suitable scope to use to find a way to solve the problems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will be discovered on the railway vehicle suspension system and its evolution of the suspension system using various types of methods. It will be focused more on the theory of railway vehicle suspension, the configuration of railway vehicle suspension, types of the railway suspension system, and the experimental works.

2.2 Theory of Railway Vehicle Suspension

A train has two suspension systems, one between wheels and bogie and one between bogie and train body. **Figure 2.1** and **Figure 2.2** shows the real arrangement of the suspension system in railway vehicles. The suspension system is very important for railway vehicles because it not only just separating the train from vibrations and bumps but it tends to decrease the forces between wheels and rail. (Presthus, 2002)

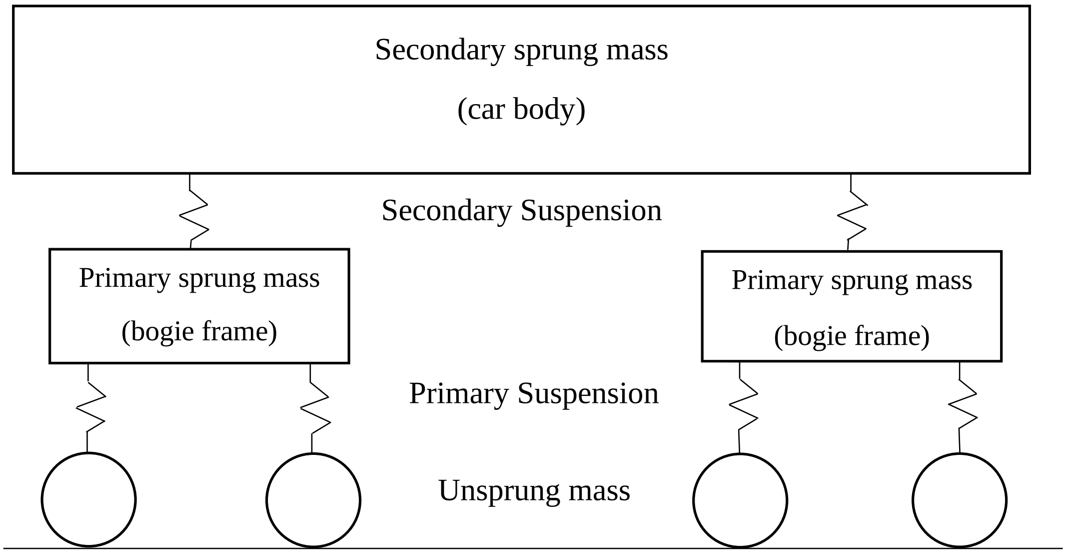

Figure 2.1 Breakdown of the mass and suspension arrangement of railway vehicles.

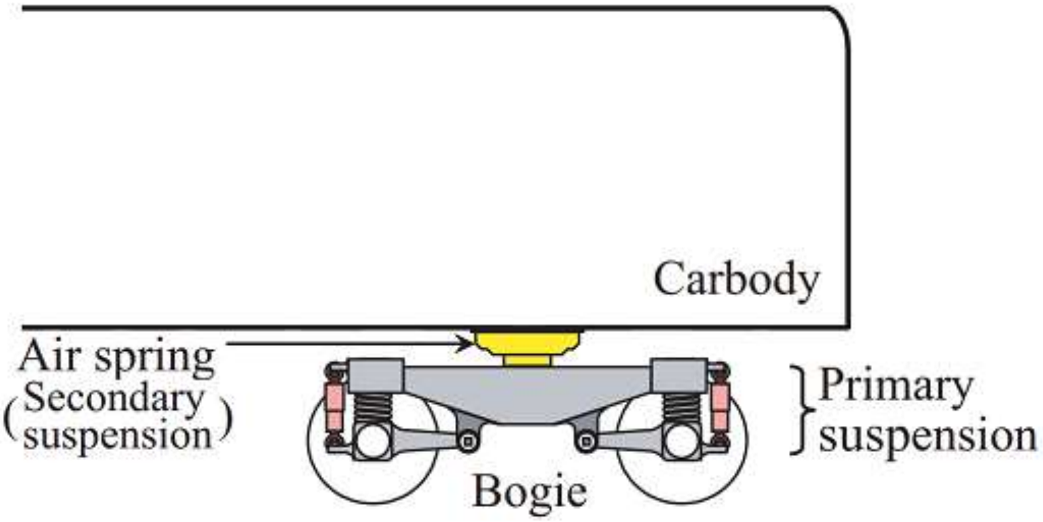

Figure 2.2 The schematic diagram of the rail suspension system. (Railsystem Website, 2020)

The secondary suspension normally consists of a pair of air springs. Usually, the air spring has a preload of 50kN to 150kN for the passenger railway vehicles. Figure 2.3 shows a bogie with two air springs. (Presthus, 2002)

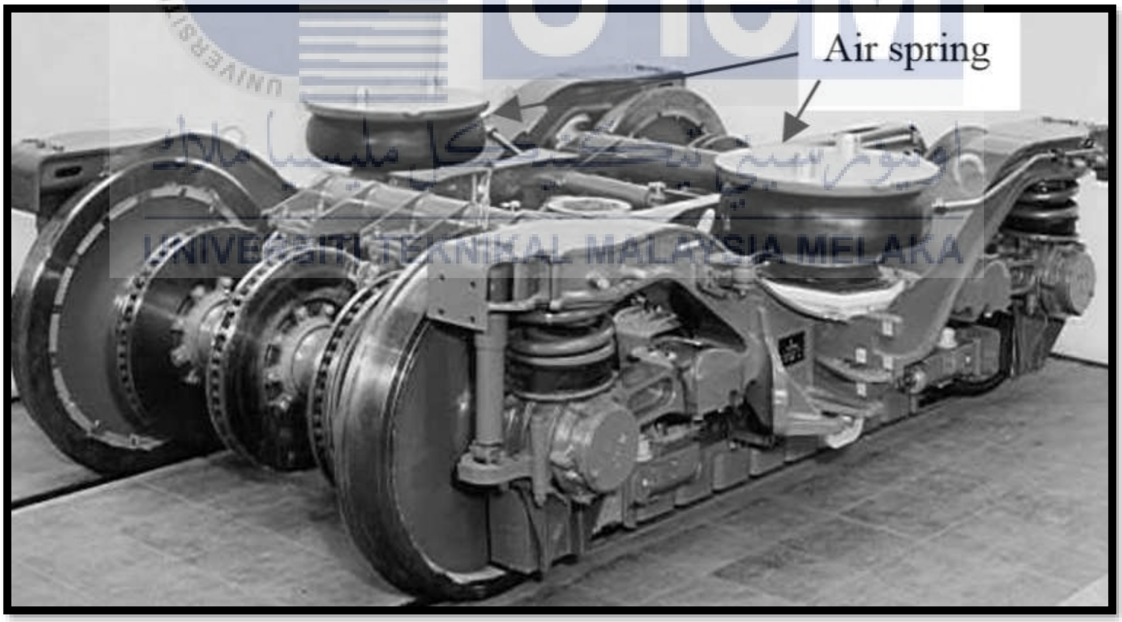

Figure 2.3 Bogie with two air springs. (Presthus, 2002)

The suspension system in railway vehicles can be springs, shock absorbers and connections system that attaches a vehicle and its wheels and enables relative motion between the two. Suspension systems must facilitate the consistency of both track surface and handling, which conflict with each other. The tuning of suspensions allows the correct compromise to be found.

The undercarriage is the train bogie and usually has four to six wheels pivoted below the end of the vehicle. Underneath the train, it's like a small truck or trolley. The truck is the standard way that most railway vehicles run. It is divided into the frame, the bolster, the pivot pin, the assembly of the wheel, the roller bearing, the brake beams, the brake block, the brake levers and the brake cylinders. **Figure 2.4** shows the simple schematic of the passenger car suspension system showing the general arrangement and location of the primary suspension springs on the axle boxes and the secondary suspension upon which the car body rests (The Railway Technical Website, 2019).

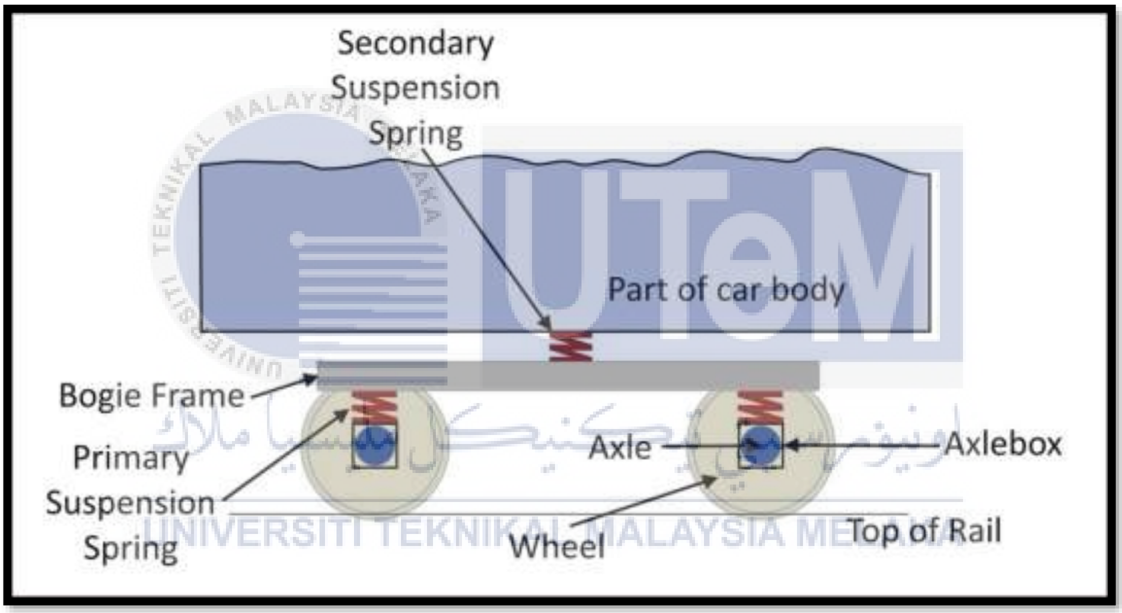

Figure 2.4 Simple schematic of the passenger suspension system. (The Railway Technical Website, 2019)

The vibration in the railway vehicle body occurs due to the track irregularities and their contact with wheels. If not contained, these vibrations will cause damage to various sections of the vehicle and also return it to the track. Such movements are found in the suspension system. Since the suspension of railway vehicles is a complicated and complex system toward accomplishing various capacities, dynamic suspension innovations with various capacities and configurations have been created in different structures. (The Railway Technical Website, 2019)

2.2.1 Configuration of railway vehicle suspension with air spring suspension

In railway vehicles, the secondary suspension aims to overcome vibration to the body from track irregularities while transferring loads with constrained deflections from the car body to the bogie. However, minor deflections are contrary to the good vibrational attenuation, restricting the effectiveness of a passive secondary suspension. The active secondary suspension can be planned at the same time to achieve the objectives. According to their shared partnership, three relevant principles regarding driving comfort, vehicle speed and track quality are improving the comfort of passenger travel at present speed and track conditions, enabling increased speed with maintained comfort of the ride and no greater demand for track quality and enabling lower track performance without sacrificing riding comfort and pace. (Bin Fu, et al, 2020).

To configure the active secondary suspension, actuators are normally positioned in a vertical direction between the bogie and the car-body. In order to control vibration in the low-frequency range, the passive air springs can also be adjusted as actuators. Bin, *et. al.* (2020) discovered that actuators will replace the existing passive springs directly from the bogie to the car body and control the movement of the vehicle independently. However, given the dynamic characteristics of the various actuators, in addition to passive springs in parallel or in sequence to complement the actuators, it is more realistic to implement the actuators. Passive springs can hold static and quasi-static loads in vertical and lateral directions as compared to actuators, which in turn decreases the need for actuators and thus allows small actuator dimensions. The passive springs can isolate the high-frequency excitations that the actuation system cannot respond to when linked in series with actuators because of its possible inefficiency in the high-frequency range. Combinations of both series and parallel springs can be used in functional applications.

Bin, *et. al.* (2020) has proposed a secondary suspension configuration that incorporates actuators between the car bodies in a train set, as shown in **Figure 2.5**. The number of actuators can be lowered in this configuration. As vibrations have been attenuated by the passive suspensions, the working environment is friendly for sensors and actuators.

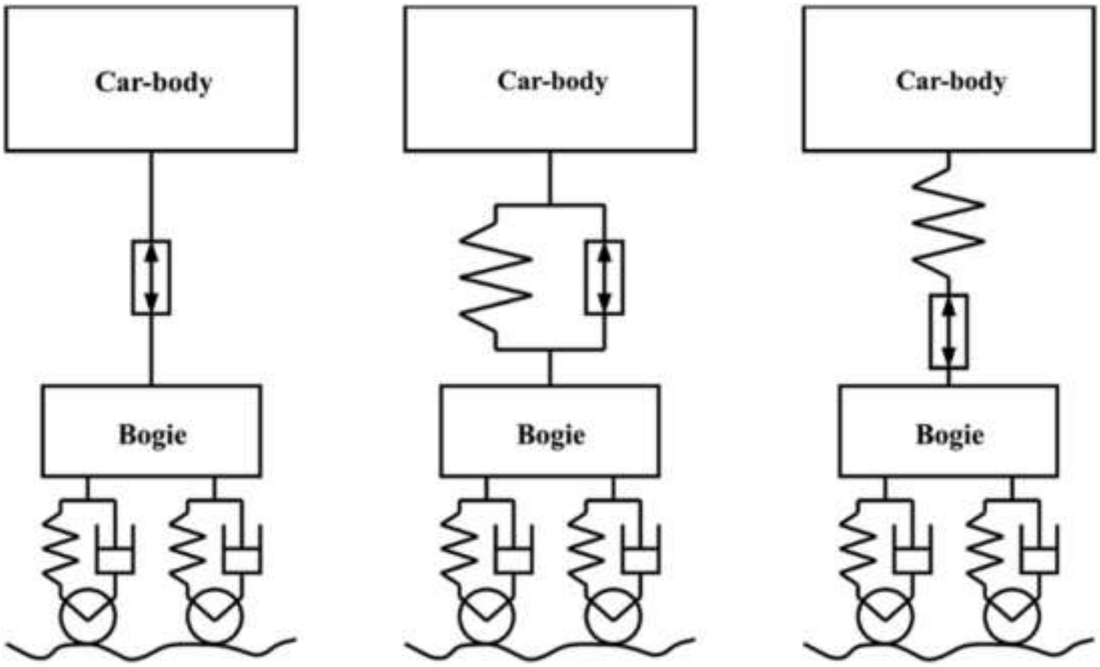

Figure 2.5 Mechanical configurations of active secondary suspension. (Bin, et. al, 2020)

2.2.2 Types of suspension system (passive, semi-active, active)

A variety of different components make up railway vehicle suspensions. This may vary from mechanically simple coil springs and friction dampers to advanced air spring arrangements, levelling valves and tanks or active or semi-active parts. In general, freight railway vehicles have fewer complex suspensions than passenger vehicles or locomotives, and while passenger vehicles typically have both the main suspension and a secondary suspension, freight vehicles (two or four axles) frequently have only one suspension layer (Eickhoff, et al. (2010). In connection to it, the suspension system can be classified as a passive suspension system, semi-active suspension system and active suspension system (Gallagher, 2015).

a) Passive suspension system

Hassan (1986) discovered that in terms of fully regulating vehicle dynamics, passive suspension systems of conventional elements (springs and dampers) have limitations. The problem emerges from vehicles usually being driven at different speeds over tracks of different qualities and requiring sufficient attitude control with load changes. The working space must, in practice, be small. Standard parameter choices for passive suspension reflect a compromise between the various specifications and are made according to the type and configuration of the vehicle. The damping value of the passive damper is determined by the total area of the orifice in the piston head (the number of holes).

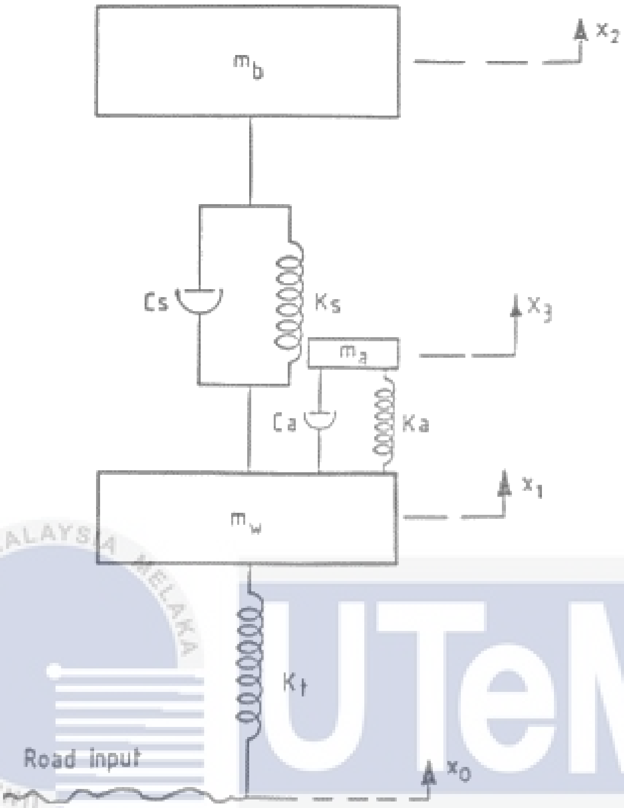

Figure 2.6 The schematic diagram of three masses passive suspension system. (Hassan, 1986)

b) Active suspension system

Gallagher (2015) said that the active suspension system uses a hydraulic actuator to decrease the amount of external power needed to achieve the desired performance characteristics and to exert an individual suspension force to boost the ride characteristics. The active suspension system can also be classified as slow active, active and fully active as shown in **Figure 2.7**.