ACTIVE SUSPENSION SYSTEM USING LINEAR QUADRATIC REGULATOR FOR A SOLID-AXLE RAILWAY VEHICLE

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ABSTRACT

In this research the active suspension system of railway wheelset system is presented. The purpose of this research is to design active suspension system for a solid-axle railway vehicle using linear quadratic regulator (LQR) method. The objective of Linear quadratic regulator (LQR) is to minimize the lateral displacement and its yaw angle of the wheelsets. This method to improve the performance of the vehicle in terms of its lateral displacement and yaw angle when the vehicle moves on a straight and curve tracks. Performance of this system has been compared with the passive suspension system. The input to the system is track irregularities, the radius curve with 1500m and cant angle with 7°. The results show that the curving performance in active suspension system is better than passive suspension system. System has been implement by performing computer simulations using the MATLAB and SIMULINK toolbox.

ABSTRAK

Tesis ini membentangkan sistem kawalan bagi suspensi aktif gandar keretapi. Tujuan projek ini adalah untuk merekabentuk sistem gantungan aktif untuk keretapi bergandar pejal dengan menggunakan pengawal kuadratik yang optimum pengatur linear (LQR). Objektif system ini untuk meminimumkan anjakan sisi dan sudut rewang daripada keretapi. Ia juga untuk meningkatkan prestasi kenderaan secara anjakan melintang (lateral) dan sudut rewang (yaw) ketika keretapi bergerak di atas landasan lurus dan selekoh. Prestasi sistem ini dibandingkan dengan sistem gantungan pasif. Masukan bagi sistem ini adalah ketidakrataan landasan, jejari selekoh 1500m dan darjah kecondongan selekoh 7°. Terdapat dua parameter yang dikawal dalam kajian ini ia adalah anjakan melintang (lateral) dan sudut rewang (yaw). Pengawal optimum (LQR) telah digunakan. Keputusan menunjukkan bahawa sistem suspensi aktif adalah lebih baik daripada sistem suspensi pasif. Prestasi sistem ini ditentukan dengan melaksanakan simulasi komputer yang menggunakan MATLAB dan Simulink toolbox.

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TITLE AND INTRODUCTION

1.1 Introduction

A railway vehicles are considered as the most important transportation systems in the modern society that connected on series of rail vehicles that move along on a track that due to its ability to give transport cargo passengers and lead heavy loads with fast, safely and low impact on the environment from one place to another place. Railway vehicles are guided by a rail. The wheels of steel are rolling on steel rails. This is also by far the most common technique for rail vehicles in the world, (Anderson and Berg 1999).

The train are provided by a separate locomotive or individual motors in self-propelled multiple units. By historical in early 19th the train are powered by the steam locomotive and most in modern train are powered by diesel and electricity locomotives supplied by overhead wires or additional rails [1].

Other than that energy sources of power were include horses, rope or wire, gravity, pneumatics, batteries, and gas turbines. In the beginning, the railway system was strictly in mechanical concept actually. Mechanised rail transport systems first appeared in England in the 1820s. However, it has to become electronically based. Basically, since the 1070s the concept of active technology in rail vehicle has been analyzed theoretically and by experimentally. It has not yet made in operational use. As defined in Figure 1.1 structural of railway vehicle has shown that this transport usually consists of two rails, two bogie, body vehicle, suspension and four wheelsets.

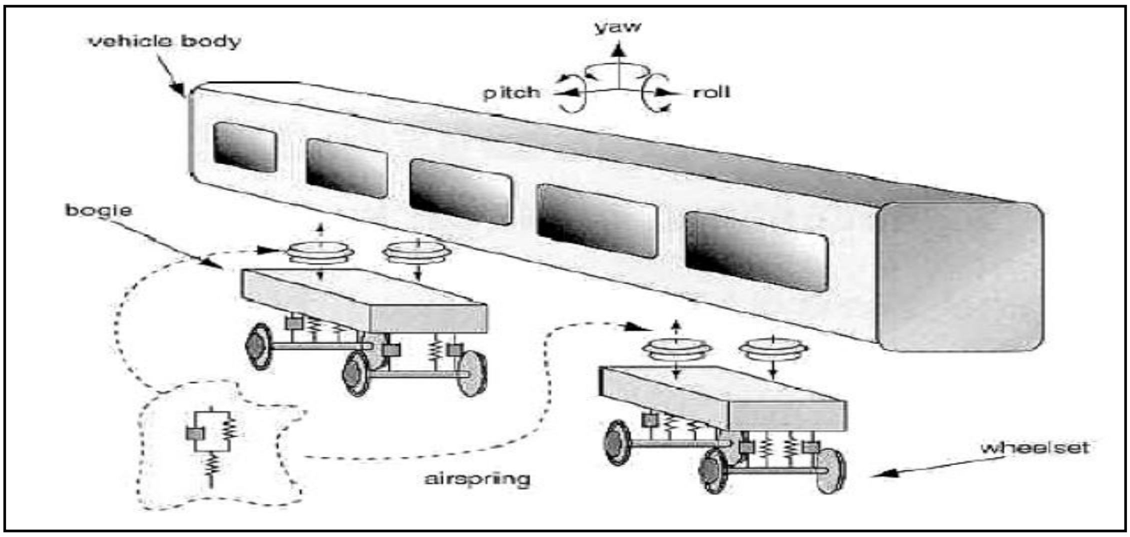

Figure 1.1 : Structural of Railway Vehicle [1]

Many countries already use rail transport as a public transport such as in Asia. In Asia many trains are used as regular transport in India, China, South Korea and Japan. It is also widely used in European countries. However accidents and incidents continue to occur. There is some causes of railway vehicle accidents. In generally its come from five categories such human factor, track defect, miscellaneous causes, equipment defect, signal defect and train control. The causes of the accidents are presented in percentage form, involving the accidents starting from 2001 to 2006 reported from National Rail Safety Action Plan Progress Report 2005-2007 Federal Railroad Administration. Other than that the cause also derailment, tracks that are unsuitable managed or maintained. The Pie Chart has been show in Figure 1.2.

According to the statistics, more than most of the accidents are caused by human factor which the largest single category of train accidents with value 38%. Then the incident followed by track defect with almost high common factor that contributes to railway vehicle accidents with the percentage of 35%. Track defect come with defect quit high causes of derailment, unstable at wheel and also lack down of force. For reduce train derailment and to provide good quality ride, it is quick importance to design suspension system. From this incident active suspension system were choose to overcome this problem.

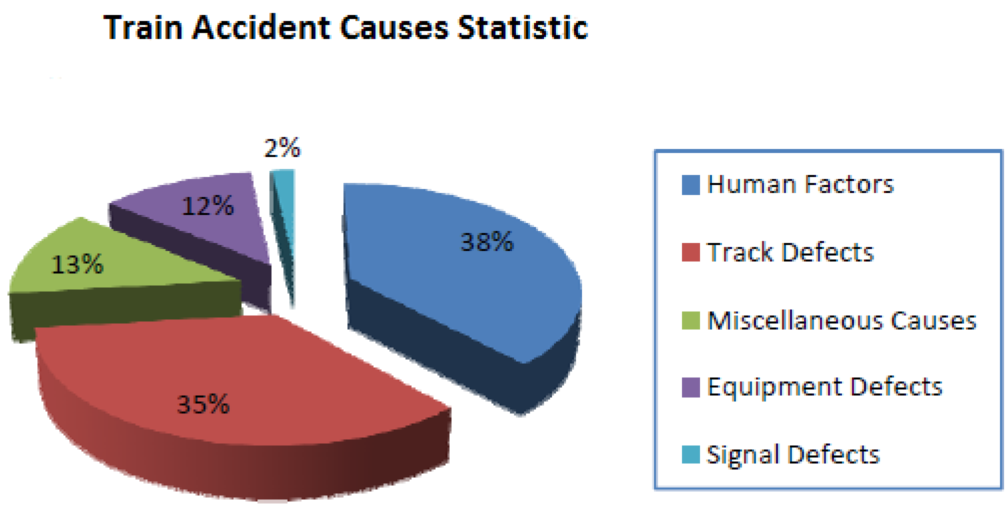

Figure 1.2 : Train Accident Cause Categories from Year 2001-2006

1.2 Railway Vehicle Suspension System

A railway vehicle suspension system basically are consists in two suspensions. That is primary suspension and secondary suspension. The primary suspensions there are connected between bogie and wheelset. This suspension system deals with running stability, curving performance and to support vehicle body. There also provide vehicle stability at high speed which amplitude very smooth. For the secondary suspension it is located underneath the vehicle body. This suspension system is very important to ensure a good quality ride and provide safe conditions of the transport good by reducing vibrations due to track irregularities. At the same time isolates the higher frequency vertical irregularities to provide a good ride quality [1].

Generally a railway vehicle very stable in a low speed but it is become unstable when the speed is increase at one point it reached. Suspension system is very important part and must designed carefully to get the vehicle stability, good quality and safe to passengers. On this researched project, only primary suspension system is discussed. Primary suspension system are contains passive primary suspension and active primary suspension.

1.3 Role of Primary Suspension

The perceived comfort level and ride stability of a vehicle are two of the most important factors in a vehicle's subjective evaluation. There are many aspects of a vehicle that influence these two properties most importantly the primary suspension components which isolate the frame of the vehicle from the axle and wheel assemblies. In the design of a conventional primary suspension system there is a trade off between the two quantities of ride comfort and vehicle stability. If a primary suspension is designed to optimize the handling and stability of the vehicle the operator often perceives the ride to be rough and uncomfortable. On the other hand if the primary suspension is designed to be the vehicle will be comfortable but may not be too stable during vehicle manoeuvres. As such the performance of primary suspensions is always limited by the compromise between ride and handling. A primary suspension can only optimized to a point.

Primary suspension is the term used to designate those suspension components connecting the axle and wheel assemblies of a vehicle to the frame of the vehicle. This is in contrast to the suspension components connecting the frame and body of the vehicle, or those components located directly at the vehicle's seat, commonly called the secondary suspension.

There are two basic types of elements in conventional suspension systems [2]. These elements are springs and dampers. The role of the spring in a vehicle's suspension system is to support the static weight of the vehicle. The role of the damper is to dissipate vibration energy and control the input vehicle. The basic function and form of a suspension is the same regardless of the type of vehicle or suspension.

1.3.1 Passive Primary Suspension

The passive suspension is a vital element of railway vehicle since railway began. It consists a passive elements and components inside. A passive suspension system are only uses mechanical springs and dampers. This element linkages to support the vehicle body and the load inside the vehicle body. However, it is difficult to achieve good ride quality, vehicle stability and curving performance for wheelset. The parameters of a primary passive suspension system are generally fixed to achieve a certain level of compromise between running stability and curving performance.

Figure 1.3 shows a plan view of passive suspension system. This configuration are mechanically simpler and lighter. It consists with vehicle body, two solid axle wheelset, spring and damper. In laterally direction, wheelsets mounted onto vehicle body via springs and dampers in lateral direction.

For passive suspension system, when a train cross over traverses at curves with very high speed, a gravity forces will be experienced by passengers. Indirectly it will also exhibit a sustained oscillation in lateral plane known as wheelset hunting. Figure 1.4 has been shows wheelset hunting.

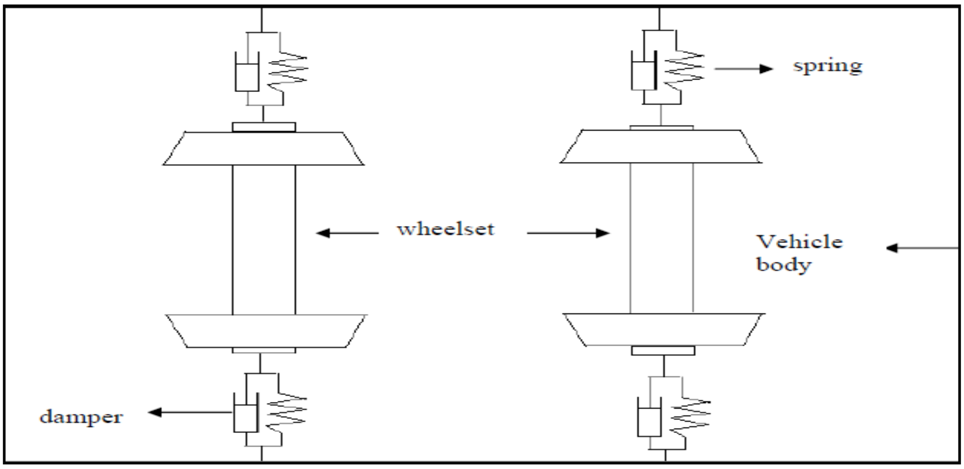

Figure 1.3 : Plan view of passive suspension system [1]

Figure 1.4 : Wheelset hunting [2]

1.3.2 Active Primary Suspension

An active primary suspension system are proposed from the weakness of passive suspension. For active primary suspension system other elements are applied. This is very important part in designing a railway vehicle. Active suspension system consists of sensors, actuators and controllers [2]. This elements were include sensor to measure and sense variable change and the actuators to apply force or torque and can increase the damping. Then controller to provide control commands for the actuators.

Active suspension have ability to supply and modulate the flow of energy. In this active suspension actuators can increase the damping and control the resonance of suspension without generating much vibration on vehicle body. Figure 1.5 shows a plan view of active suspension system [3].

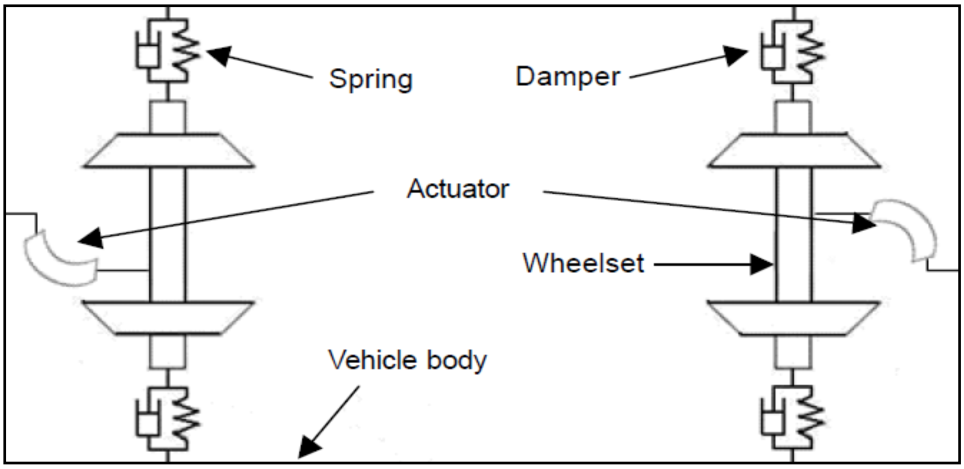

Figure 1.5 : Plan view of active suspension system [3]

1.4 Project Background

This research studied on controller design and modelling the active suspension control system of solid axle railway vehicle in straight and curved track. The actual parameters are used in this project to get an actual performance for the solid axle railway vehicle. Different values of inputs track irregularities are use to get the feedback result from wheelset lateral displacement and wheelset yaw angle. To overcome this problem active suspension systems are used Linear Quadratic Regulator (LQR) in solid axle railway vehicle for minimize lateral displacement and its yaw angle of the wheelsets. It also to improve performance of the vehicle on straight and curve tracks. The linear state-space structure was designed by using MATLAB software.

1.5 Problem Statement

The crucial part component in railway vehicle system is the wheelset. It consists of two coned (otherwise is profiled) shaped wheel that connected to an axle. Usually the inner side of the wheel has a large radius wheel flange compared to the outer side of the wheel. Figure 1.6 show the solid-axle railway vehicle features. Here when train meet a curved track corner, the wheelset and the rails have a certain consideration to make sure a good performance and safety journey of a train. Figure 1.7 show the curved track when train moving along it.

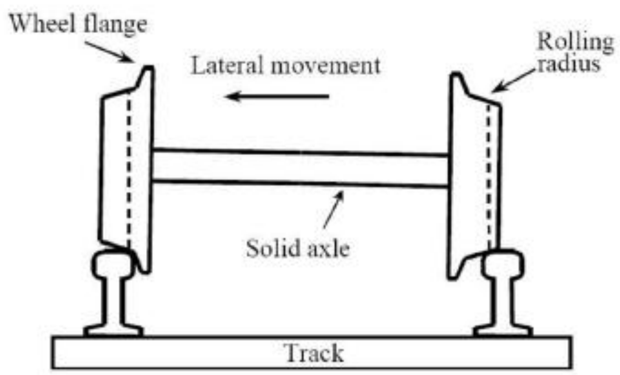

Figure 1.6 : Features of Solid-Axle Railway Vehicle [4]

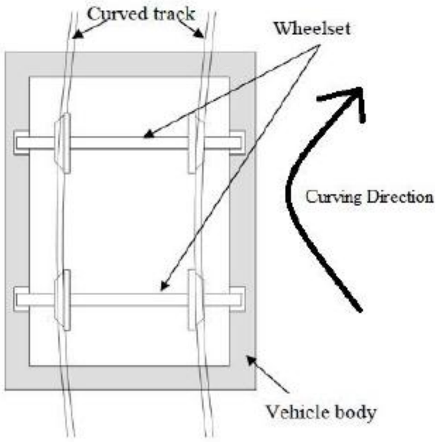

Figure 1.7 : Train moving along curved track. [4]

This project is a study of suspension system that commonly applied on solid-axle railway vehicle. Since the project of solid-axle railway vehicle have been done by using passive suspension system and another method before, therefore this is the main reason to develop this project in order to create and design by using linear quadratic regulator (LQR).

The problem that encourages developing on this project is to minimize lateral displacement and its yaw angle. Passive suspension system only used mechanical springs and dampers where it is use for transmit curving forces and to give stabilise in wheelsets. Here, active suspension systems are being experimented to solve this design problem.

Other than that the purpose of this project is to improve the performance of the vehicle on straight and curve tracks. So by using this active railway vehicle, the performance of railway vehicle suspension can be improved. Passive system has difficult to achieve good ride and vehicle stability. Anyway to get the best solution of it, the performance between active suspension systems with passive suspension system will be compared.

1.6 Objective of Project

The objectives are as follow :

1. To design a Linear Quadratic Regulator (LQR) for solid-axle wheelset suspended to ground by using mathematical description to stabilize the wheelset.
2. To investigate the improvement of curving performance on solid-axle wheelset suspended to ground through Linear Quadratic Regulator (LQR) control.
3. To analyze the performance of Linear Quadratic Regulator (LQR) by using computer simulation.

1.7 Scope of Project

The scope of project are following :

1. Description of solid-axle wheelset suspended to ground to minimize lateral displacement and its yaw angle of wheelsets.
2. Analyze the performance of wheelset due to variations in track irregularities and velocity 60m/s.
3. Use MATLAB to simulate and analyze the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is the required path or process that done with reading, analysis, research proposals and often a chapter in research and dissertations. It is very important and critical point of current knowledge about a specific topic. From literature review the information obtained from the study can be used for this research.

Generally, the purpose of a review is to analyze critically a segment of a published body of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles.

This chapter will discuss about literature review from paper that has been read and related with this project. All the paper were related and compared between different studies by research.

2.2 Research of Literature

By doing the research many journals that have been read. Active suspension system of railway wheelset system has been choose [1]. An active suspension system are adds the actuators, a controller and sensors to an existing passive system. This elements were include sensor to measure and sense variable change and the actuators to apply force or torque and can increase the damping. Controller are used to provide control commands for the actuators. Advantages of active suspension system are low natural frequencies. The performance between active and passive performance of wheelset in terms of lateral displacement and its yaw angle was evaluated. Controller that have been used to control the system are Fuzzy Logic Controller and Optimal Controller. Logic Controller and Optimal Controller are illustrated to highlight the advantage and disadvantages for both of controllers. As a result Fuzzy Logic Controller shows a good and better performance compared to Optimal Controller. Fuzzy Logic Controller has a advantages like it is so simple to design, improve control performance and mathematical model is not required.

Railway vehicle consists set of primary and secondary suspension system. In primary suspensions systems its deal with running stability of vehicle [2]. By the way for secondary suspension system its transmits low frequency movement so that the vehicle follow the track and at same time isolates higher frequency irregularities to provide a good ride quality. For passive suspension system its only used springs and dampers to stabilise wheelsets. But it's so difficult to achieve in a good ride and stability of vehicle. The wheelset curving performance also be simultaneously when only used passive suspension system. So to improve all of this weakness, active suspension system are being used to provide this problem. Here the application control are used like sensors, actuators and electronic controller. They have 3 types of railway vehicle that have been used. Its consists bogie-based vehicle with solid-axle wheelsets, two-axle vehicle with solid-axle wheelsets and two-axle vehicle with IRWs. The paper mention that two-axle railway vehicle system with solid-axle wheelsets features vehicle without any bogie. Vehicle body connected directly to wheelsets via primary and secondary suspensions. It's for reducing weight and complexity. Following in this paper, maximum allowable cant deficiency is 177.8mm, cant angle 7º and curve radius is 1500m. As a result, during curving two-axle vehicle performs better than bogie-based vehicle especially when minimum wheelset lateral displacement. Other than that IRW give better curving performance than solid-axle wheelset.

In journal form [3], the method that have been used are linear quadratic regulator (LQR) and particle swarm optimization (PSO). When designing linear quadratic regulator for railway vehicle system, the system must be assume in linear. The lateral displacement of wheelset relative to the track and its yaw angle are main concern so LQR needs be modified. By using PSO method, its represented by a particle in search space. This particle have one assigned vector that's called velocity vector. PSO algorithm initialized with iteration = 0, velocity = 0 and position = random position with population optimization technique. This particle are to be optimized at its current location at every iteration. In this paper as mention before, PSO technique are used to find most optimum weighting matrices (Q and R) for linear quadratic controller to minimize lateral displacement and its yaw angle. On the result, LQR by using PSO give better performance compare to trial and error method. PSO more systematic and control performance can be improved. Otherwise, the curving performance between passive and active suspension system are compared. For performance, an active suspension system performs better than passive suspension system. On another hand the active suspension system employing LQR able to maintain stability of vehicle during curving.

Solid axle wheelset is critical component in modern railway vehicle [4]. This solid axle consists of two coned or profiled wheels that rigidly connected by axle. The specific problem of estimate wheel rail parameters as vehicle run along the track and also how to achieve effective control of this components has been proposed. Here when active control are applied to stabilise a solid axle wheelset in travelling at high speed on straight track with lateral irregularities, it is possible to estimate the varify values of this wheelset conity (λ), longitudinal creep coefficients (f11) also lateral creep coefficients (f22). Linear Quadratic Regulator (LQR) has been used to estimated and changing wheelset parameters values to maintain its stability. It also to stabilise the wheelset suspended to ground and to a secondary mass. In LQR the time varying is satisfied. This wheelset are assumed to be traveling at 83m/s (300km/h) on straight track with lateral irregularities. To solve this problem two method is adopted namely Least-squares error (LSE) and Least-absolute error (LAE) to avoid problems associated with control and identification of continous time system in discreate time.

The Least-absolute error (LAE) in second order spline-based interpolation give better estimate of varying wheelset parameters. Other than that when compare with passive suspension the LQR provide better performance in smaller relative lateral displacement on the straight track with random values of lateral irregularities.

This paper purpose the procedure to estimate conity (λ), longitudinal creep coefficients (f11) also lateral creep coefficients (f22) [5]. The Continuous- Time Recursive Least Absolute Error (C-T RLAE) with Variable Forgetting Factor (VFF) method to estimate solid axle wheelset parameter in Linear Quadratic Regulator (LQR) of two axle railway are presented. The Continuous- Time Recursive Least Absolute Error (C-T RLAE) with Variable Forgetting Factor (VFF) are used to overcome this bias problem. The Continuous Time Recursive Least Absolute Error (C-T RLAE) are designed for Linear time invariant (LTI) system but the Variable Forgetting Factor (VFF) are used for time varying system. The performance of Continuous Time Recursive Least Absolute Error (C-T RLAE) originally and Continuous- Time Recursive Least Absolute Error (C-T RLAE) with Variable Forgetting Factor (VFF) methods are compared. Linear Quadratic Regulator (LQR) was applying to stabilise wheelset traveling especially at high speeds wheelset parameters. Continuous- Time Recursive Least Absolute Error (C-T RLAE) with Variable Forgetting Factor (VFF) methods give good estimated of railway wheelset compared Continuous- Time Recursive Least Absolute Error (C-T RLAE). From this combination from (C-T RLAE) with (VFF) can reduce estimation bias.

The main systems on railway vehicle were approach in suspension, traction and braking system [6]. Here on suspension system has greater interest and partly because it is more fundamental to complete vehicle design. On the railways, the vehicle mechanically design are very simple. Its only have boxes on to sets of wheel and have poor in their performance. For primary suspension characteristic, primary suspension that's from wheels to bogie is to fairly stiff. Besides that, the damping secondary suspension difficult design trade-off. If too low, that have a lot of activity in resonant modes but if too high the dampers transmit high frequency track movements to vehicle body. Here when a wheelsets on straight track, this wheelset were runs in their own wheel flange. By the way if wheels moves faster along the tracks, the wheelset will go around the curve. From this issues, software tools that has been used are DLR development.

2.3 Introduction Of Railway Vehicle

Railway vehicle or train is one of transportation that connected on series that move along on the track that's function to give transport of passengers or freight from one place to another place. It is very suitable transport especially for travelling in long distance and also short distance. This is because railway vehicle provides more comfortable journey to the passengers with less expensive compared to travelling by using airplanes, buses and others. There are 2 types of travel by train. It is short distance purpose and long distance purpose.

2.3.1 Short Distance

In with short distance travel it can be divided into rapid transit, commuter rail and also monorail.

2.3.1.1 Rapid Transit

A rapid-transit also has been called as underground, subway, elevated railway or metropolitan railway system is a passenger transport system in an urban area with a high capacity and frequency. It is a grade separation from other traffic. Rapid transit systems are typically located either in underground tunnels above street level. Outside urban centers rapid transit lines may run on grade separated ground level tracks.

2.3.1.2 Commuter Rail

The commuter rail that also called as suburban rail is a passenger rail transport service that primarily operates between a city centre and other the middle to outer suburbs or other locations. Its beyond 15 km. It is used for people who travel on a daily basis. The speed of this train are slower where it varies from 50 to 200 km/h (30 to 125 mph). Its operations are follows a schedule. Commuter rail trains differ from other short distance train because they are being larger, provide more seating and less standing room, have a lower frequency of service and also have scheduled services.

2.3.1.3 Monorail

A monorail is a rail-based transportation system based on a single rail. Its acts as its sole support and its guide way. The term of monorail variously to describe the beam of the system or the vehicles travelling on such a beam or track. The system of this transportation is often referred to as a railway. To differentiate monorail systems from other transport modes are that the beam in a monorail system is narrower than the vehicle.

2.3.2 Long Distance

Long distance trains is the trains that can travel between many cities and regions of a country. Other than that sometimes the trains can cross several countries. For long distance train they often have a dining car or restaurant to allow passengers to have a meal during the course of their journey. Beside that long distance train also have sleeping cars at the train for whose need travels overnight. This train can be divided into high-speed trains and maglev.

2.3.2.1 High Speed Trains

A high-speed train is one intended for regular operations at speeds of over 200 km/h with a high level of service and generally comprising multi powered elements. The high speed trains are electrically driven via overhead lines and electrical is the main source to generate. In high speed trains for the track it uses the continuous welded rail for allow the trains to exceed the speed and to reduces the track vibrations.

2.3.2.2 Maglev

Maglev also known as Magnetic levitation are transportation that has been researched for years in order to achieve faster operation over 500km/h. This kind of transport used the electromagnetic concept by using levitation from a very large number if magnet for lifting and propulsion. This method has the potential to achieve faster, smoother and quieter response. The speed for this type can exceed 581km/h and therefore it is not used for inner-city mass transit.

2.4 Type of Active Primary Suspension System

As mention before passive suspension are most widely used in many country for long time ago. For improve the weakness of passive primary suspension system, the active primary suspension system are chosen to provide a performance. There are many types of configuration for the active primary suspension and each of this configuration option have their own purposes.

There are to give a good performance of railway vehicle by using technologies such as the pneumatic, hydraulic, electromechanical and actuators. The types of the active primary suspension system are shown below :

(a) Solid axle wheelset suspended to ground
(b) Active-stabilized wheelset
(c) Independent rotating wheelset
(d) Actively-steered wheelset

2.4.1 Solid Axle Wheelset Suspended to Ground

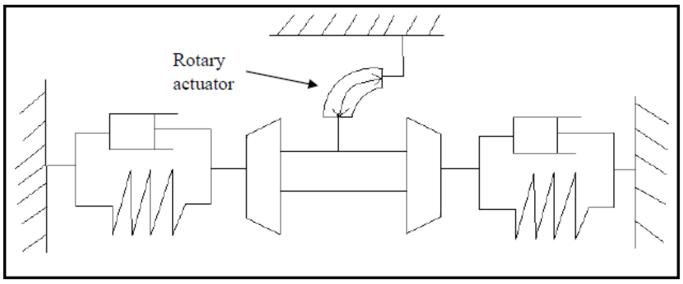

Figure 2.1 : Solid Axle Wheelset Suspended to Ground [1] [6]

The Figure 2.1 has show a schematic diagram of solid axle wheelset suspended to ground. From this figure, the model have two damper that connected in parallel with two spring and also has the actuators. The actuators are used to apply a yaw torque to the wheels of this system [4].

2.4.2 Active-stabilized Wheelset

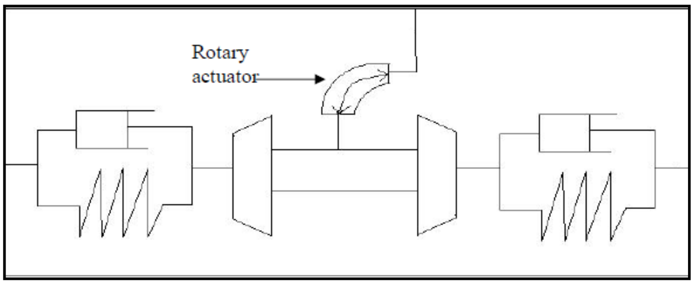

Figure 2.2 : Active-stabilized Wheelset [1] [6]

In wheelset arragement on Figure 2.2 show a schematic diagram of Active-stabilized Wheelset. the function of a rotary actuator in this system is to attached each wheelset in railway vehicle system. The concept of this rotary actuator is to apply a yaw torque to the wheelset which is proportional to lateral velocity of wheelset. Here the system will produce an active damping for stabilizing and not interface with natural curving [5].

2.4.3 Independent rotating wheelset

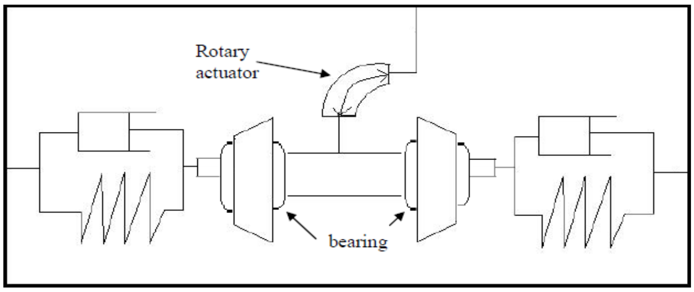

Figure 2.3 : Independent Rotating Wheelset [1] [6]

Independent Rotating Wheelset is third types of the active suspension. This wheelset arragement has shown in Figure 2.3. This wheelset arrangement are same like wheelset arrangement in an active-stabilized wheelset but for this system its implemented by applying bearings to the wheelset.

Actually this applications propose wheelset and both of wheels are free to rotate independently on axle. Here its function for remove the instability. For the actuators, its job to approached to steer wheelset through the curve. Furthermore, this arrangement has their own disadvantage. The natural curving action is no longer present because between both of wheels are not connected [6].

2.4.4 Actively-steered Wheelset

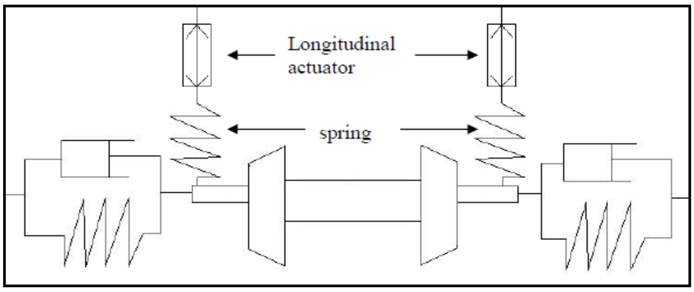

Figure 2.4 : Actively-steered Wheelset [1] [6]

Figure 2.4 show the Actively-steered Wheelset. On this schematic diagram, the longitudinal springs are connected in series with actuator that attached to the wheelset. The idea is the higher frequency oscillations of the wheelset are stabilised by the spring with the low bandwidth active control provided by actuators. It essentially to relax the force they produce when vehicle goes round curves so as to allow wheelset to take up its natural curving position.

Actually, this wheelset arrangement is simple system because does not have a rotary actuator and yaw torque are not applied. Furthermore, this arrangement has their own advantage. There is posses extremely good performance with simple control laws are include on this system advantages.

2.5 Advantage of Active Primary Suspension

The passive primary suspension system has difficult problem to archive good ride and vehicle stability because its only uses mechanical springs and dampers. Other than that it's also has limitation and weakness on the system. From here that why many researchers focused on active primary suspension system. An active primary suspension system has more advantages compared to passive suspension. The following are advantage of the active primary suspension system :-

(a) Continually supply and modulate the flow of energy.

(b) Low dynamic deflections particularly under conditions of transient excitations

(c) To eliminate body roll during cornering.

(d) Suspension characteristics are maintained regardless of loading variations.

(e) Low natural frequencies, which the result in greater passenger comfort while still maintaining small static deflections.

(f) High speed of response to any input and high flexibility in the choice of dynamic response especially different modes of the vehicle.

2.6 Railway Vehicle Configuration Design

Railway vehicles carrying passengers with good run on tracks which provide the support and guidance functions. Figure 2.5 shows Railway vehicle configuration. There is the vehicle body for the passengers. This vehicle body is supported by two bogies where each bogie having 4 wheelset (two pairs) of wheels. Each pairs connected by solid axle wheelset. Primary suspension are from the wheelset to the bogie that mainly dealing with running stability. For the secondary suspension are from bogie to vehicle body which ensure the passengers experience a good ride quality.

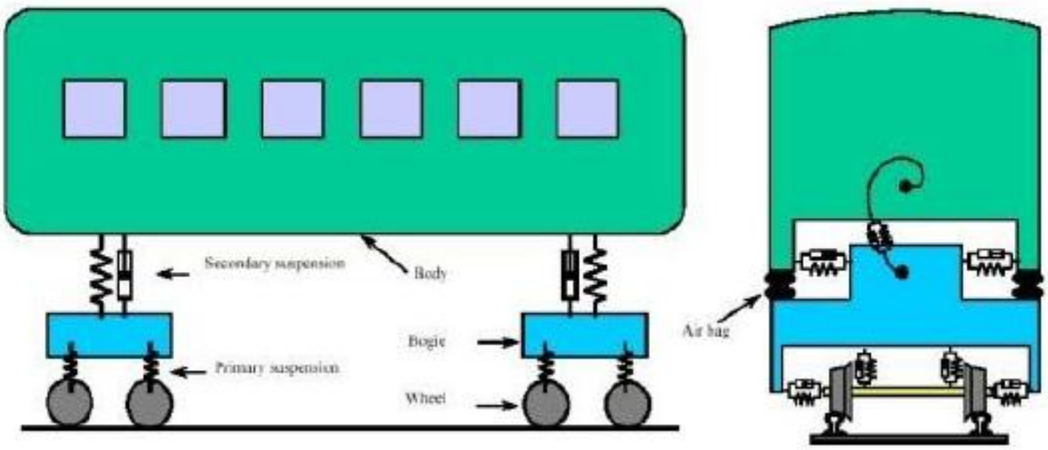

Figure 2.5: Railway vehicle configuration [7]

2.7 Railway Wheelset Dynamics

It is very important to understand the railway wheelset works. Figure 2.6 are consists of mechanical structure of a conventional bogie. When the vehicle travelling on straight track, each wheel will rotate with rotational position and automatically the distance between two wheels will be maintained. But if vehicle travelling in curve track, the problems will arise. The problems is the wheelset will move outwards and this can cause the outer wheel to run on larger radius and the inner wheel run on smaller radius. This phenomena can cause derailment.

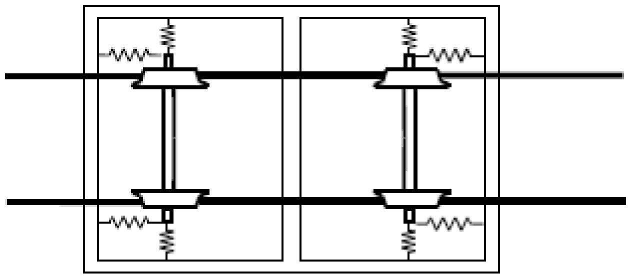

Figure 2.6: Railway vehicle configuration [6][7]

2.8 Component of Railway Vehicle

Basically the most important component of railway vehicle is the wheelset. Wheelset are consists with two coned wheel that were connected to axle. Here both of wheel are depends by each other. When the train has meet a curve track, the inner side of the wheels has a larger radius wheel flange compared to the outer side of the wheel. From this component the lateral displacement and yaw angle can be studies.

Figure 2.7 show lateral displacement and its yaw angle for solid axle railway vehicle. When the train meet a curved track corner, wheelset and the rails have a certain consideration to make sure a good performance of a train.

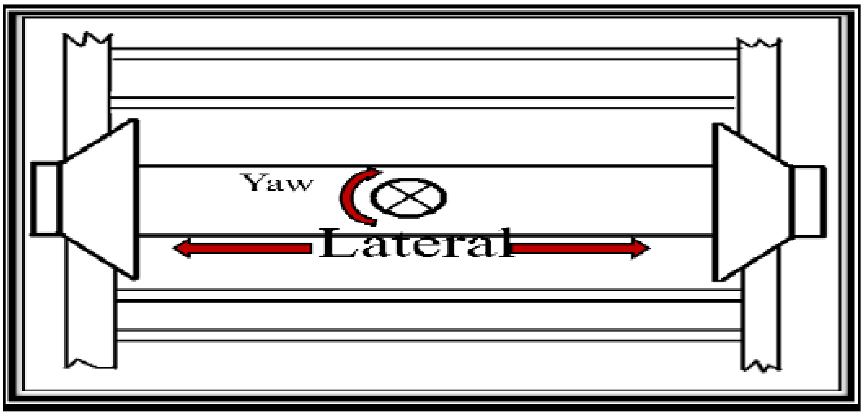

Figure 2.7 : Lateral displacement and yaw angle for solid axle railway vehicle [7]

2.9 Railway Track Profile

The most important characteristic to design a good performance of railway vehicle element is the track. Come with good track and minimization of irregularities will be guide and automatically avoid railway vehicle from accident and derailment.

2.9.1 Track Irregularities

The track input to vehicles comprise into two types. There are the deterministic and random track input. In this project the random track input which know as track irregularities is considered. This track irregularities is exist in both on straight and curves track [7].

2.9.2 Curve Radius and Cant Angle

To study the suspension curving performance, the track input of this system is curve track with a radius and its cant angle. The curved track is connected to straight track. The curved track is canted inwards to reduce lateral acceleration experienced by passengers [8]. Here radius curve track was 1500m and cant angle was 7°. Curved tracks are made if they are required to change the route or changes in the route direction. The curves are avoided as much as possible because a combination of centrifugal and gravitational forces act on the vehicle and the passengers themselves forcing them onward of the curve. However, if the cost of heavy earthwork to obtain straight track is high, the curves become necessary. Cant is defined as the elevation of the outside rail minus the elevation of a curved track [9]. The vehicle speed (e.g. balance speed) on curved track can be determined from the following balance equation (2.1).

$$V_{bal} = \sqrt{R \text{ x } g \text{ x } tan\theta_c}$$
(2.1)

where;

V is the balance speed (ms)

R is the curve radius (m)

g is the gravity (9.81 ms)

θ_c is the cant angle (deg.)

When the vehicle travers a curve, its transmits a centrifugal force to the rail at the point of wheel contact. This force is function of the speed of the vehicle, severity of the curve and the mass of the vehicle. This force acts at the center of gravity of the rail vehicle. Its resisted by the track. If the vehicle is travelling fast enough, it may derail. Cant also called as super elevation is defined as the elevation of the outside rail minus elevation of a curved track It can reduce the centrifugal force, where the outer rail is raised above the level of the inner rail by certain amount [10].

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