A SIMULATION STUDY OF RAILWAY VEHICLE DYNAMICS PERFORMANCE

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"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of
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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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Marcus Tullius Cicero, a Roman philosopher once said “gratitude is not only the greatest of virtues, but the parent of all others”. Here, I want to express my infinite gratitude to Allah S.W.T for strengthen my religious hence prevent me from give up while facing all these challenging working environment. For my beloved mother, a special thanks from me for giving full support along this industrial training period.

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ABSTRACT

Railway vehicle is just another type of transportation system among many other such as automobile, aircraft, etc. When it comes to the vehicle, of course it will implicate motion. Something that produce a motion will create what we called dynamic behavior. It is often for the people to get to know about automobile dynamic because automobile was familiar with our daily life. We always use this type of transportation system, hence get the feel about its dynamic condition although not many people will concern about it.. Railway vehicle is actually just the same with automobile which has dynamic behavior like vertical, lateral, rolling and pitching motion. It uses the suspension system that same with the automobile in the term of technology, but just the design and placement of component are different because obviously these two types of vehicles have different shape and handling systems. Railway vehicle is one of the most efficient transportation systems nowadays. Aside from having the lowest accident rate, it was really a good choice for a people that want a fast and comfortable ride. To provide comfortable in a high-speed railway vehicle, a good study on the railway vehicle dynamic performance is a need in order to develop the better system. Inside this text, the dynamic performance of the railway vehicle will be studied. The study has a scope to examine and analyze the passive system of railway vehicle. It is included deriving a mathematical model for the railway vehicle and using the simulation to get the result hence predicting the performance of the railway vehicle. From the analysis, suitable controller will be fitted into the system to improve the existing passive system. It is whether a semi-active, active or fully active control system depending on their pros and cons. All of this action was necessity in order to create a nice and comfort ride for the railway vehicle passenger.

ABSTRAK

Keretapi merupakan salah satu sistem pengangkutan di antara sistem pengangkutan yang ada seperti otomobil, pesawat udara dan lain-lain lagi. Apabila kita berbicara mengenai kenderaan, sudah pasti ia akan melibatkan pergerakan. Sesuatu yang menghasilkan pergerakan akan mewujudkan apa yang dipanggil perilaku dinamik. Ia adalah perkara biasa untuk seseorang mengetahui mengenai dinamik otomobil kerana kita sudah biasa meggunakannya setiap hari sehingga kita dapat mearasai keadaannya walaupun sesetengah orang tidak ambil peduli mengenainya. Keretapi sebenarnya mempunyai sifat yang lebih kurang sama seperti otomobil seperti pergerakan menegak, sisi dan berpusing. Ia juga menggunakan system suspense yang sama dengan otomobil dari sudut teknologi, tetapi dari sudut rekaan dan kedudukan komponen adalah berlainan. Keretapi merupakan salah satu kenderaan yang paling efisien pada hari ini. Selain daripada statistic kemalangan yang rendah, ia juga menjadi pilihan untuk mereka yang mahukan perjalanan yang pantas dan selesa. Kajian yang teliti mengenai prestasi dinamik keretapi amatlah penting untuk menghasilkan keselesaan menaikinya. Di dalam laporan ini, prestasi dinamik keretapi akan di pelajari dan di kaji. Skop pembelajaran dan kajian adalah merangkumi kajian dan analisis untuk sistem pasif keretapi. Ia termasuklah menghasilkan model matematik untuk keretapi dan meggunakan simulasi untuk mendapatkan keputusan lalu meramalkan prestasi keretapi itu. Dripada analisis yang dibuat, system kawalan yang sesuai akan dipasang kepada system yang sedia ada. Ia samada system separuh aktif, aktif ataupun aktif sepenuhnya, bergantung kepada kesesuaian keadaan. Semua ini amatlah penting untuk menyediakan perjalanan yang selesa dan bagus di dalam keretapi.

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EMS	=	Electromagnetic suspension
EDS	=	Electrodynamic suspension
DOF	=	Degree of freedom
MR	=	Magneto rheological
c	=	Damping coefficient, Ns/m
k	=	Spring stiffness, N/m
f_{0y}	=	Creep force, N
m_c	=	Carbody's mass, kg
m_t	=	Truck's mass, kg
m_w	=	Wheel's mass, kg
z	=	Vertical displacement, m
$\dot{z}$	=	Vertical velocity, m/s
$\ddot{z}$	=	Vertical acceleration, m/s^2
y	=	Lateral displacement, m
$\dot{y}$	=	Lateral velocity, m/s
$\ddot{y}$	=	Lateral acceleration, m/s^2
$\emptyset$	=	Angle, degree
F	=	Force, N
f	=	Hydraulic actuator force, N
I	=	Moment of inertia
k_p	=	Proportional gain
k_i	=	Integral gain
k_d	=	Derivative gain

e	=	Error

CHAPTER 1

INTRODUCTION

1.0 Introduction

1.1 History of Railway Vehicle

Railway vehicle is the most common transportation method to deliver goods and transporting passengers. Ever since an Englishman Richard Trevithick has built the first steam railway locomotive in 1804 as shown on **Figure 1.1**, the development in rail transportation technology has rapidly increase with the existing of high-speed train powered by magnetic levitation (Maglev Train) on 20th century as shown on **Figure 1.2**.

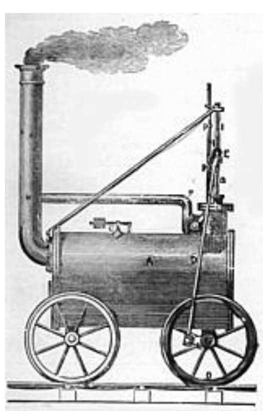


Figure 1.1: The locomotive of Trevithick, 1804

Source: www.history.rochester.edu

Figure 1.2: Maglev train at Japan

Source: www.herebeanswers.com

When the “father of steam locomotive”, George Stevenson of England built a steam locomotive on 1829, its velocity only reaches 45km/h but nowadays, a maglev train at Japan can reach a velocity of 581km/h. It was about 12 times faster than Stevenson’s locomotive. As train operating speed increases from time to time, safety and comfort was still become a priority for the manufacturer. High-speed train nowadays has been built with the system developed by their engineers to decrease the potential of derailment. On the other hand, comfort on the railway vehicle can be achieved by minimize the effect of vibration and noise occur.

Modern railway vehicle has become faster and efficient, so the mechanical system also becoming more complex. Thus, the system can be better analyze, develop and improve using mathematical and computational approach. Then, a mathematical model is developed and simulated using simulation software. The comfort level of the railway vehicle is improved from the result of model analysis.

Vehicle dynamic which focus on ground vehicle especially automobiles was already become a wider niche that known by people. The reason behind this fact is that automobile is widely used by the people around the world and by using this type of vehicle almost every day, they can feel and learn about dynamic condition of their vehicle. Even their knowledge about automobile was far-out from what other people can think because automotive was such a huge industry and news about it was so accessible.

As for the railway vehicle, train or locomotive that usually used for going back to hometown at the weekend or during a festive season, the most obvious thing that we can see different from automobile is it’s moving along a track and its motion is also control by the track direction. The limitation of knowledge about this industry was cause by train and locomotive service and technology in this country that still left-behind if compared to a country such as Japan and France. At Japan, they have the busiest and modern train system while France has TGV which mean high-speed train that can compete with Japan train technology.

Actually, railway vehicle has same dynamic characteristic with automobile which is rolling motion, pitch motion, lateral motion, longitudinal motion, etc. When the train moves in linear direction, it has longitudinal motion on it. Then, if the train moves in nonlinear direction, as same as automobile the train will have rolling and lateral motion on it. When the train arrives at their station and brake was applied towards it, then of course there will be pitch motion on the vehicle.

1.2 Problem Statement

Railway vehicle was a commonly used transportation system. The movement of the railway vehicle along the track (linear / non-linear) has produced a lot of disturbance e.g. vertical, rolling, lateral motion etc. That disturbance has even more increase for the high-speed railway vehicle and has brought such disadvantages as the railway vehicle stability and passenger comfort has become priority these days. As for this reason, dynamic behavior of the railway vehicle will be analyzed and suitable controller will be design to improve ride handling.

1.3 Objectives

- To derive a mathematical model of the railway vehicle model.
- To study and analyze the model via equation of motion and simulation process.
- To develop suitable controller hence improving the existing passive system.

1.4 Scopes

- The railway vehicle model used to create the mathematical model is a 6-DOF system of a half-car model.
- The simulation process was done inside Matlab Simulink.
- The parameters are taken from the real Keretapi Tanah Melayu Berhad (KTMB) railway suspension.

CHAPTER 2

LITERATURE REVIEW

2.0 Literature Review

2.1 Introduction

Engineering have such a various type of niche in the term of its dynamical system and railway vehicle dynamic is one of the most complex systems within it. There is much condition on it that must be count in and put into consideration, such as the contact between the wheel and rail that generate different forces in different kind of speed and the interaction between the wheel and rail that involve complex geometry of both side as we can see flange shape on its wheel.

2.2 Railway Wheelset

Wheelset is the basic component for running on the train. It is two wheels that assemble on both end of an axle and it is fixed to ensure both roll with common angular velocity and the distant between the wheels is remain constant. From the early railway vehicle age until now, there is a development and evolution of wheelset design and it has come to the most practical and efficient design as shown on **Figure 2.1**.

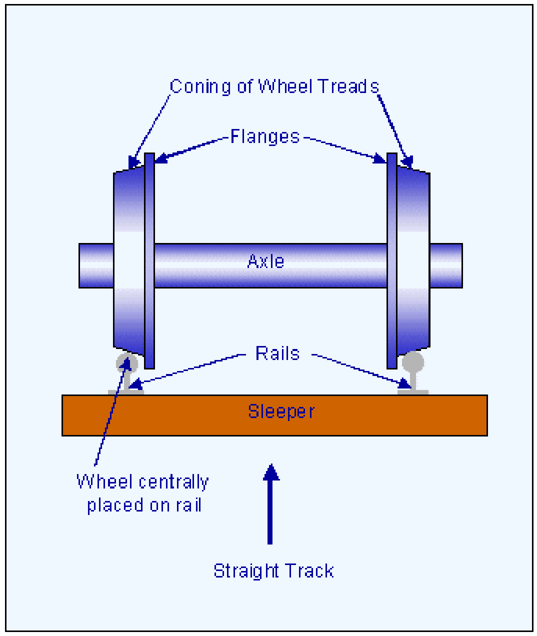


Figure 2.1: Railway wheelset

Source: www.railway-technical.com

On the early years of railway, as the speed of the vehicle was low, they were just focus on reducing rolling resistance so that the load carried can be multiple. Then, further research has been taken out based on more broad aspect as the speed start to be the important thing. The basic shape of the railway wheelset is that it has conical tread and the flange is inside the rail. Though it seems to be a simple design, the fact is such a various design has actually carried out before in order to achieve the design that can roll steady and stable on the rail with a very low potential of derailment.

There is a tough reason for the wheelset to be design that way. The flange has been put into wheelset design in the early of 17th century. The position of the flange, whether on the inside, outside or on both sides has become controversial into the 19th century. It was then the conical shape of the tread has been introduced in order to reduce the rubbing on flange to the rail. This shape was also design to ease the motion of the railway vehicle on the curve track. It is not known when the coned shape first introduced that it is actually would naturally provide smooth curve by combining it with a flange inside. On the year of 1821, the concept of coning of the wheel tread was stated by George Stephenson in his “Observations on Edge and Tram Railways”;

According to George Stephenson (1821) - "It must be understood the form of edge railway wheels are conical that is the outer is rather less than the inner diameter about 3/16 of an inch. Then from a small irregularity of the railway the wheels may be thrown a little to the right or a little to the left, when the former happens the right wheel will expose a larger and the left one a smaller diameter to the bearing surface of the rail which will cause the latter to loose ground of the former but at the same time in moving forward it gradually exposes a greater diameter to the rail while the right one on the contrary is gradually exposing a lesser which will cause it to loose ground of the left one but will regain it on its progress as has been described alternately gaining and loosing ground of each other which will cause the wheels to proceed in an oscillatory but easy motion on the rails."

Stephenson's description has clearly told us for what is today called kinematic oscillation. This was shown on **Figure 2.2** below.

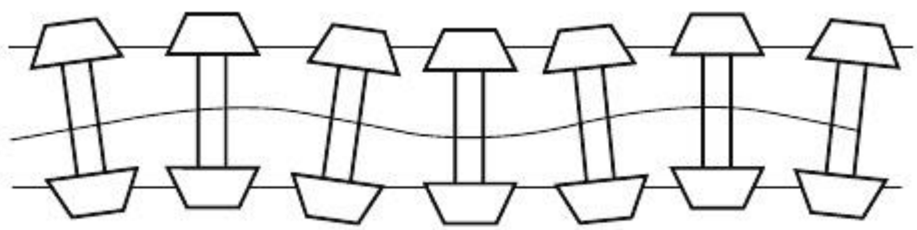
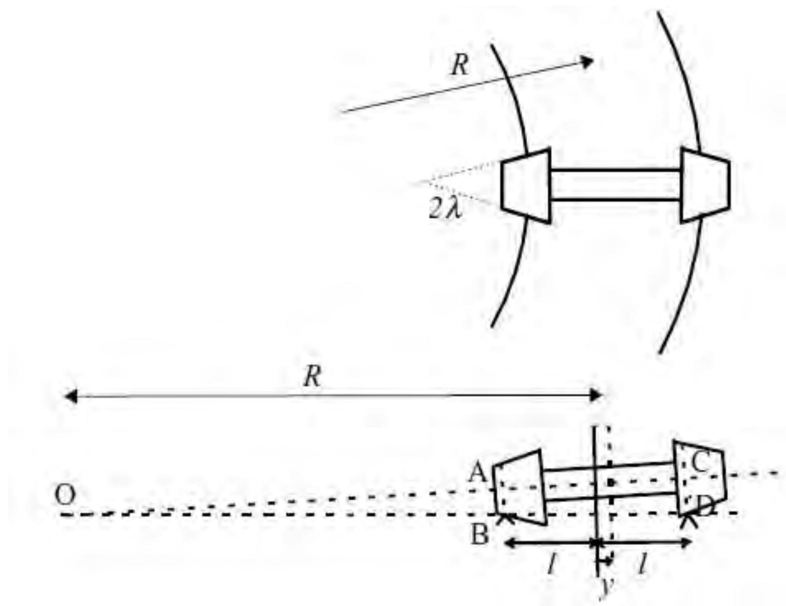


Figure 2.2: Kinematic oscillation of a wheelset

Source: Handbook of Railway Vehicle Dynamics, Google Docs

A wheelset with a coned shape on its wheel that traveled on a curve track can have consistent pure rolling motion if it moves outwards and get in a radial position. On 1855, Redtenbacher has provided a theoretical analysis as shown on **Figure 2.3**.



$$OAB = OCD$$

$$\frac{r_0 - \lambda y}{R - l} = \frac{r_0 + \lambda y}{R + l}$$

$$y = \frac{r_0 l}{R\lambda}$$

Figure 2.3: Redtenbacher's formula for the rolling of a coned wheelset on a curve.

Source: Handbook of Railway Vehicle Dynamics, Google Docs

Based on **Figure 2.3** above, it show the simple geometric relationship between lateral movement of the wheelset on a curve, y, the radius of the curve, R, the wheel radius, r_0, the lateral distance between the points of contact of the wheels with the rail, $2l$, and the conicity, λ, of the wheels in order to sustain pure rolling Usually a wheelset can only roll round on a moderate curves without flange contact, and a more realistic consideration of curving requires the analysis of the forces acting between the vehicle and the track.