

SUPERVISOR DECLARATION

“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 Bachelor of Mechanical Engineering (Automotive) with Honours.”

Signature:

Supervisor:

Date:

RAILWAY VEHICLE DYNAMICS AND VIBRATION ANALYSES

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**This thesis is submitted as part of the fulfilment for the bestowal of Bachelor in
Mechanical Engineering (Automotive) with Honours**

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DECLARATION

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

Signature:

Author:

Date:

Specially dedicated to supervisor and beloved family

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ABSTRACT

Final Year Project is a subject with research and scientific relevant compulsory for the final year student to take part as the fulfilment for the bestowal of degree course in Faculty of Mechanical Engineering, UTeM. Project entitled “Railway vehicle dynamics and vibration analyses” is a meant to study the behaviour of railway vehicle in term of roll and vibrations at three perpendicular axes during curve track. The result of measured vibration will be used to generate ride index formulation. Review on previous study on railway dynamic analysis, optimization of suspension, ride comfort and instrumentation are carried out as to expose fundamental on how the methodology is involved and executed. During experimental gathering, proper instruments and tools are required to obtain the data. Sensors and DAQ are the main components while PC installed with NXT 2.0 and MATLAB is used for the file-build, data logging and further analysis event. Graph is presented for better understanding and observation is made for the analysis. Ride index formulation is based on formula reasoning where the standard deviation of the vibration responses had been used as the boundary for comfort zone.

ABSTRAK

Projek Sarjana Muda merupakan satu subjek yang berunsur kajian ilmiah dan saintifik kepada pelajar tahun akhir dalam proses memperolehi pengijazahan Sarjana Muda di Fakulti Kejuruteraan Mekanikal, UTeM. Tajuk projek bernama “Dinamik kenderaan berlandas dan analisis getaran” bertujuan untuk mendapatkan respons kenderaan berlandas dalam bentuk rebanan pada ketiga-tiga paksi yang berserenjang dan gulingan di landasan yang lengkung. Keputusan respons kenderaan berlandas akan digunakan untuk memperoleh perumusan indeks tunggangan. Perolehan terhadap kajian yang dibuat sebelum ini termasuk bidang analisis dinamik kenderaan berlandas, optimasi terhadap suspensi, penyelesaian tunggangan dan instrumentasi memdedah kaedah-kaedah yang boleh diaplikasikan nanti. Semasa eksperimen, penggunaan instrumen dan alat yang betul adalah penting untuk mendapat data yang jitu. Penderia dan system perolehan data merupakan alat yang memainkan peranan penting sementara komputer bersertakan NXT 2.0 dan MATLAB digunakan untuk pembinaan fail, penyimpanan dan analisa yang seterusnya. Graf akan digunakan untuk memudahkan penonjolan terhadap getaran-getaran yang dianalisa. Perumusan indeks tunggangan dibuat adalah berdasarkan penghujahan formula di mana sisihan piawai dari geratan digunakan sebagai limitasi zon penyelesaian.

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LIST OF SYMBOLS

DOF	Degree of Freedom
a_x	Longitudinal acceleration
\emptyset	Roll
a_y	Lateral acceleration
θ	Pitch
φ	Yaw
DAQ	Data acquisition system
mm	millimetre
MATLAB	Matrix Laboratory
%	Percent
F_R	Rolling resistance force
m	Mass
g	Gravity constant
f_r	Rolling resistance coefficient
C	Constant
v	Speed of train
Hz	Hertz
ISO	International Standard Organization
K_{px}	Primary longitudinal suspension stiffness
ARMS	Autonomous ride monitoring system
FRA	Federal Railroad Association
CRE	Centre for Railway Engineering
CQU	Central Queensland University
PK-PK	Peak to peak
RMS	Root mean square
FFT	Fast Fourier Transform

Wz	Sperling's ride index
a	Peak acceleration
f	Frequency
$F(f)$	Frequency dependent weighting factor
B	Weighing factor
V	Voltage
g	Gravity constant
USB	Universal Serial Bus
AC	Alternating Current
RAM	Random Access Memory
GUI	Graphical User Interface
°	Degree
d_i	Deviation of each measurement
\bar{d}	Mean deviation measurement
g	Gravity constant
m/s^2	Meter per second squared
\ddot{x}	Acceleration
\dot{x}	Velocity
x	Displacement
c	Damper coefficient
k	Spring stiffness
J	Moment of inertia
$\ddot{\theta}$	Angular acceleration
$\dot{\theta}$	Angular velocity
θ	Angular displacement
CPM	Cycle per minute
km	kilo meter
km/h	kilo meter per hour
FBD	Free Body Diagram
EOM	Equation of Motion
GPS	Global Positioning System
PC	Personal Computer
KTM	Keretapi Tanah Melayu

ETS	Electric Train Service
LRT	Light Rail Transit
ERL	Express Rail Link
KLIA	Kuala Lumpur International Airport
CG	Centre of Gravity
cm	centi meter
t	Time integral upper limit
t_o	Lower limit
y_o	Initial condition
y	Magnitude at that instant
F	Force
K_p	Primary suspension stiffness
C_p	Primary suspension damping coefficient
K_s	Secondary suspension stiffness
C_s	Secondary suspension damping coefficient
$^{\circ}/s$	Degree per second
A	Measured value
SDK	Suite Development Kit
s	second

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Commercial railway transportation had the capability to mitigate congestion on other transit system seeing that highway and air travel systems are started to be constrained in many countries due to the early infrastructure designs [1]. In the meantime, there has been a great boost in the railway network to meet the growing demand [2]. Railway transportation will be a suitable selection for substituting airplane for long journey travel after the depletion of fossil fuel in the coming few decades. Current research and development on railway transport is striving for improved riding comfort, higher speed, cost reduction, safety and first-rated punctuality [3].

The railway vehicle running along a track is one of the worldwide interested engineering studies [4]. Track configuration in terms of profile and gradient had work as the input disturbance toward the car body while bogie and suspension function as the transmitting medium. Study on mode of motion or also known as degree of freedom (DOF) as shown in **Figure 1.1** is imperative to attain excellent manipulation on railway vehicle control.

Longitudinal acceleration, a_x is the motion variable that directs toward where the railway vehicle is heading. Roll, θ (radian) is the angle difference between the carriage and reference plane at this axis. Lateral acceleration, a_y is the motion variable occurring from the side of the railway vehicle whereby a rotating angle at

this axis is known as pitch, θ (radian). Vertical acceleration, a_z described as up-down motion in the same direction as vertical axis. Yaw, φ (radian) is the angular difference of carriage and reference plane at this axis.

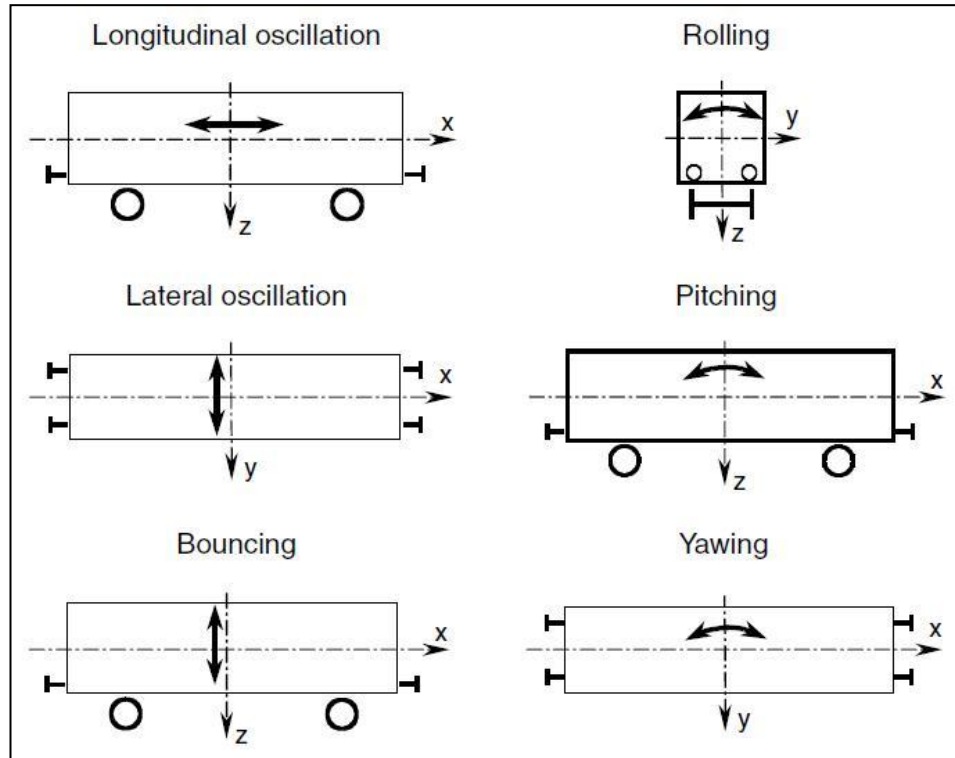


Figure 1.1: Illustration on carriage six modes of motion [4]

1.2 PROBLEM STATEMENT

There is change in carriage velocity and moving direction when a commercial railway vehicle is subjected to a curve from a certain velocity. At that instant, it experiences significant roll, lateral acceleration and longitudinal acceleration.

Kicked in lateral (centripetal) force with the inherent longitudinal momentum of the railway vehicle excites resultant force acted towards the railway vehicle itself, minimizing the wheel-rail contact during flange up-climb event as shown in **Figure 1.2** and causes arduous ride and handling. Roll happens when there is lateral weight shift at the wheel [5]. These modes of motions eventually transmitted to the car body

and passengers (loads). In fact, excessive momentum during cornering ascends the risk of derailment catastrophes and passenger's ill-comfort.

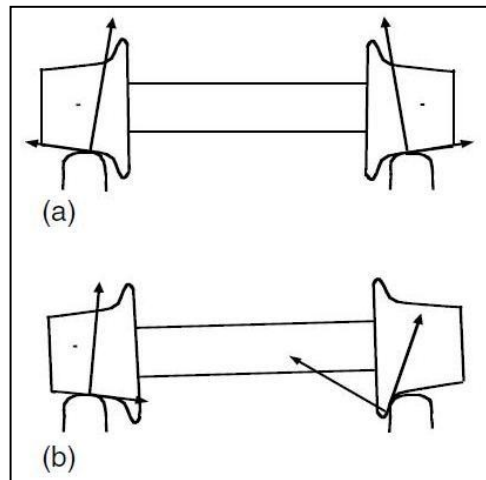


Figure 1.2: Wheel set profile at (a) straight track and (b) curve track [4]

1.3 OBJECTIVES

The objective of this thesis is to determine the dynamic performance of commercial railway vehicle in term of roll and acceleration in three respected axis during cornering. Subsequently, it is aims to come out with the ride index formulation of commercial railway vehicle at the straight track and curve track.

1.4 SCOPE

For the start up, experiment data on commercial railway carriage's rolling and acceleration responses are collected by using data acquisition system (DAQ) during straight track and curve track. The selected railway line shall be intercity type along with the utilization of standard gauge track (1435 mm width). The collected data is analysed with MATLAB's functions to obtain its dynamics trend at the curve.

CHAPTER II

LITERATURE REVIEW

2.1 RAILWAY DYNAMICS

When a railway vehicle is moving, air resistance and rolling resistance are the two inherent existed components that oppose the tractive force regardless of track profile and condition. Air resistance for an empty wagon train is higher than a fully loaded train due to turbulent circulation of air occur in the empty wagon. Improper arrangement of goods at the flat car induced air drag phenomenon as shown in **Figure 2.1**, concentrating the load at the centre will brought up to 25% reduction of air resistance. However, rolling resistance for empty train is lower than a loaded train as weight is a function of rolling resistance as shown in Equation 1. The general formula for rolling resistance shown is applied with the condition of no slip and skid between wheel-rail interactions. Slips normally happen at the driving wheels during acceleration and skid during braking [6].

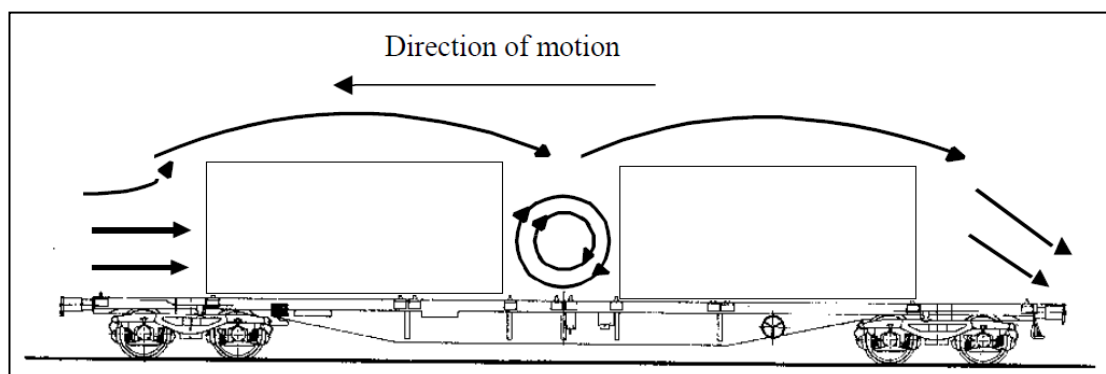


Figure 2.1: Schematic air flow around a container on flat car [6]

$$F_R = f_r mg \quad (1)$$

Where

$$f_r = C_0 + C_1 \left(\frac{v}{v_0}\right) + C_2 \left(\frac{v}{v_0}\right)^2 \quad (2)$$

f_r is the rolling resistance coefficient in %

C_0 , C_1 and C_2 are constant in %

v is the speed of train in m/s

v_0 is $27.78 m/s$ (or equivalent to $100 km/h$)

On straight track, wheelset run in centralized position, both the flanges from the left and right wheel stay at the same distant from the rail track ideally. Wheel rail contact time and magnitude indeed contributed disturbance toward car body. For bending track, wheelset will move laterally opposite to the bending direction. Wheelset coning configuration provides higher resulted linear velocity at the outer wheel as to turn the carriage in its vertical axis. Parenthetically, low conicity is crucial for high speed running yet it constrains the curving performance. Wheel tread gradient (wheel conicity) of 1:40 was used in Shinkansen as to minimize the effect of lateral oscillation without compromising issue of unbalance wheel wear [7]. Severe worn wheelset and small difference of rolling radius promote reduction in self-steering ability [8].

Hunting is the effect of lateral translation and yaw rotation of wheelset and bogie as shown in **Figure 2.2**, largely made by the coupled creep forces and mutual geometry of wheel and rail profiles [9]. Hunting phenomenon can be observed when bogie oscillates severely in lateral direction, causing passenger discomfort, track impact and derailment cases.