DYNAMIC ANALYSIS OF TRAMCAR SUSPENSION SYSTEM

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DEDICATION

To my beloved mother and father, my wife, and my baby boy

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ABSTRACT

Suspension system plays an important role in the performance of a vehicle, especially the vehicle handling and ride comfort. The objective of this project is to analyse the passenger ride comfort of a tramcar manufactured by UTM. Numerical analysis was performed on the tramcar suspension system, where the system was modelled and simulated. A full car model was successfully developed, and validated using available experimental data from the work published by other researcher. MATLAB Simulink software was used to simulate the system and obtain the system response. The comfort level was evaluated based on the displacement and acceleration response, considering the bouncing, pitching and rolling factors. The simulation results for tramcar suspension system were then evaluated by comparing them with simulation results for Proton Waja 1.6 and available standards. Based on the evaluation, the conclusion on the tramcar ride comfort was made. It was concluded that the tramcar ride comfort is comparable to the ride comfort of a Proton Waja, and is at an acceptable level. The role of suspension spring stiffness in relation to ride quality was also analysed. From the suspension parameter analysis, it was concluded that the ride comfort of the tramcar can be improved to an optimum level by having the lowest practical spring stiffness value. The tramcar suspension spring stiffness was said to be already in the region of the lowest practical value in the sense of avoiding a very low natural frequency assimilated to motion sickness. Some suggestions have been made at the end of the report for possible improvement or extension to this study.

ABSTRAK

Sistem gantungan memainkan peranan penting dalam pencapaian sesebuah kenderaan, terutamanya kawalan kenderaan dan keselesaan perjalanan. Objektif projek ini adalah untuk menganalisa keselesaan perjalanan penumpang bagi sebuah *tramcar* yang telah direkabentuk oleh UTM. Bagi mencapai objektif ini, analisa dinamik telah dijalankan ke atas sistem gantungan *tramcar* tersebut. Analisa numerikal telah dijalankan di mana satu model '*full car model*' kepada sistem gantungan *tramcar* tersebut telah berjaya dibentuk dan disimulasikan. Simulasi ke atas model berkenaan telah dijalankan dengan menggunakan perisian MATLAB Simulink. Tahap keselesaan penumpang telah dianalisa melihat kepada reaksi anjakan dan pecutan, mengambil kira faktor '*bouncing*', '*pitching*' dan '*rolling*'. Keputusan simulasi ke atas sistem gantungan *tramcar* tersebut telah dinilai berdasarkan keputusan simulasi untuk Proton Waja 1.6 dan juga penemuan pengkaji lain. Daripada penilaian yang dibuat, telah disimpulkan bahawa tahap keselesaan tramcar adalah setanding dengan tahap keselesaan Proton Waja, dan berada dalam tahap yang baik. Hubung kait antara kekenyalan spring dengan keselesaan perjalanan turut dianalisa. Daripada keputusan analisa, dirumuskan bahawa keselesaan perjalanan boleh ditingkatkan ke tahap optimum dengan mengurangkan kekenyalan spring ke tahap yang terendah. Kekenyalan spring sistem gantungan *tramcar* didapati telahpun berada di paras paling rendah sebelum frekuensi menjadi terlalu rendah yang akan menyebabkan ketidak selesaan. Beberapa cadangan telah dikemukakan pada akhir laporan berkenaan kemungkinan-kemungkinan untuk melanjutkan lagi kajian yang telah dibuat.

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LIST OF SYMBOLS

C_s	-	Suspension Damping
$C_{s\ f}$	-	Suspension Damping (front)
$C_{s\ l}$	-	Suspension Damping (left)
$C_{s\ r}$	-	Suspension Damping (rear) – (for pitch mode)
$C_{s\ r}$	-	Suspension Damping (right) – (for roll mode)
$C_{s,fr}$	-	Front right suspension damping
$C_{s,fl}$	-	Front left suspension damping
$C_{s,rr}$	-	Rear right suspension damping
$C_{s,rl}$	-	Rear left suspension damping
$F_{s,fr}$	-	Suspension force at front right corner
$F_{s,fl}$	-	Suspension force at front left corner
$F_{s,rr}$	-	Suspension force at rear right corner
$F_{s,rl}$	-	Suspension force at rear left corner
$F_{t,fr}$	-	Tyre force at front right corner
$F_{t,fl}$	-	Tyre force at front left corner
$F_{t,rr}$	-	Tyre force at rear right corner
$F_{t,rl}$	-	Tyre force at rear left corner
I_c	-	Pitch Inertia
$I_{c\ r}$	-	Roll Inertia
I_{xx}	-	roll axis inertia
I_{yy}	-	pitch axis inertia

K_s	-	Suspension Stiffness
$K_{s\ f}$	-	Suspension Stiffness (front)
$K_{s\ l}$	-	Suspension Stiffness (left)
$K_{s\ r}$	-	Suspension Stiffness (rear) – (for pitch mode)
$K_{s\ r}$	-	Suspension Stiffness (right) – (for roll mode)
$K_{s,fr}$	-	Front right suspension spring stiffness
$K_{s,fl}$	-	Front left suspension spring stiffness
$K_{s,rr}$	-	Rear right suspension spring stiffness
$K_{s,rl}$	-	Rear left suspension spring stiffness
K_t	-	Tire Stiffness
$K_{t\ f}$	-	Tyre Stiffness (front)
$K_{t\ l}$	-	Tyre Stiffness (left)
$K_{t\ r}$	-	Tyre Stiffness (rear) – (for pitch mode)
$K_{t\ r}$	-	Tyre Stiffness (right) – (for roll mode)
$K_{t,fr}$	-	Front right tyre stiffness
$K_{t,fl}$	-	Front left tyre stiffness
$K_{t,rr}$	-	Rear right tyre stiffness
$K_{t,rl}$	-	Rear left tyre stiffness
L_f	-	Distance between the front and the C.G of sprung mass
L_r	-	Distance between the rear and the C.G of sprung mass
M_c	-	Sprung Mass
M_s	-	Sprung Mass (Wheel)
M_s	-	Sprung mass
$M_{t\ f}$	-	Unsprung Mass (front)
$M_{t\ l}$	-	Unsprung Mass (left)
$M_{t\ r}$	-	Unsprung Mass (rear) – (for pitch mode)
$M_{t\ r}$	-	Unsprung Mass (right) – (for roll mode)
M_u	-	Unsprung Mass (Load on one wheel)
$M_{u,fr}$	-	Front right unsprung mass

$M_{u,fl}$	-	Front left unsprung mass
$M_{u,rr}$	-	Rear right unsprung mass
$M_{u,rl}$	-	Rear left unsprung mass
W_l	-	Distance between the left and the C.G of sprung mass
W_r	-	Distance between the right and the C.G of sprung mass
$Z_{g,fr}$	-	Front right road/ground displacement
$Z_{g,fl}$	-	Front left road/ground displacement
$Z_{g,rr}$	-	Rear right road/ground displacement
$Z_{g,rl}$	-	Rear left road/ground displacement
$Z_{s,fr}$	-	Front right sprung mass displacement
$Z_{s,fl}$	-	Front left sprung mass displacement
$Z_{s,rr}$	-	Rear right sprung mass displacement
$Z_{s,rl}$	-	Rear left sprung mass displacement
$Z_{u,fr}$	-	Front right unsprung mass displacement
$Z_{u,fl}$	-	Front left unsprung mass displacement
$Z_{u,rr}$	-	Rear right unsprung mass displacement
$Z_{u,rl}$	-	Rear left unsprung mass displacement
$\dot{Z}_{s,fr}$	-	Front right sprung mass velocity
$\dot{Z}_{s,fl}$	-	Front left sprung mass velocity
$\dot{Z}_{s,rr}$	-	Rear right sprung mass velocity
$\dot{Z}_{s,rl}$	-	Rear left sprung mass velocity
$\dot{Z}_{u,fr}$	-	Front right unsprung mass velocity
$\dot{Z}_{u,fl}$	-	Front left unsprung mass velocity
$\dot{Z}_{u,rr}$	-	Rear right unsprung mass velocity
$\dot{Z}_{u,rl}$	-	Rear left unsprung mass velocity
$\ddot{Z}_s$	-	Sprung mass vertical acceleration at the centre of gravity

$\ddot{Z}_{u,fr}$	-	Front right unsprung mass vertical acceleration
$\ddot{Z}_{u,fl}$	-	Front left unsprung mass vertical acceleration
$\ddot{Z}_{u,rr}$	-	Rear right unsprung mass vertical acceleration
$\ddot{Z}_{u,rl}$	-	Rear left unsprung mass vertical acceleration
θ	-	Pitch angle at body centre of gravity
ϕ	-	Roll angle at body centre of gravity

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CHAPTER 1

INTRODUCTION

A driver judges his vehicle based on subjective aspects. Vehicle dynamic characteristics including ride and handling have a major impact on this evaluation. For this reason, vehicle manufacturers have grown investments in order to improve this vehicle dynamic behaviour (Persegium et al., 2003). The perceived comfort level and ride stability of a vehicle are the 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 the wheel assemblies. In the design of conventional primary suspension system there is a trade off between the two quantities of ride comfort and vehicle stability. A suspension may be optimised for handling performance, or it may be optimised to isolate the occupants from road disturbances, but it cannot excel at both. In practice, the performance of conventional vehicle suspensions is a compromise between ride and handling (Kazemi et al., 2000, and Tener, 2004). If a suspension is designed to optimise the handling and stability of the vehicle, the passenger often perceives the ride to be rough and uncomfortable. On the other hand, if the suspension is designed to optimise the comfort level, the vehicle will be comfortable, but may not be too stable during vehicle manoeuvres.

Focusing on the aspect of ride comfort, the quality referred to as "ride comfort" is affected by a variety of factors, including high frequency vibrations, body booming, body roll and pitch, as well as the vertical spring action normally associated with a smooth ride. If the vehicle is noisy, if it rolls excessively in turns, or lurches and pitches during acceleration and braking, or if the body produces a booming resonance, the passengers will experience an "uncomfortable ride." The intention of this study is to perform dynamic analysis on a suspension system, analysing the relationship between the parameters of the suspension system with the factors affecting ride comfort that was mentioned above.

While there have been many studies performed on the more advanced suspension systems, such as the active or semi active suspension, this study will focus only on the passive suspension system. One of the reasons is that in this study, the analysis performed is on an existing vehicle that uses a passive suspension system. Furthermore, even though the use of microprocessors combined with technologies developments in actuators, adjustable dampers, and variable springs has led to an upsurge of more advance suspensions such as fully active and semi active suspensions, vehicles with passive suspension system are still likely to dominate high volume passenger car production for the foreseeable future (Olatunbosun and Dunn, 1991).

This study will focus on the suspension system of a non-commercial transport for recreational purposes designed by the Mechanical Engineering Faculty of Universiti Teknologi Malaysia (UTM), which is commonly known as ‘tramcar’. The vibration level the passengers of the tramcar are exposed to would be the focal point. Other factors affecting ride comfort including body pitch and roll will also be looked into.

As mentioned above, the tramcar is a non-commercial transport for recreational purposes. It was designed for the use inside a zoo, airport, around a hotel, golf resort and multi-level company to fetch customers. The tramcar is a simple car; it does not have any special technology installed onto it. To achieve its recreational purpose, tramcar does not have any door and safety belt. It makes it easier for the passenger going up and down the vehicle. The tramcar have eight seats; two including the driver’s seat in the front row, three in the middle row, and three in the last row. The tramcar uses Toyota ST 190 MacPherson strut on its both suspension systems. MacPherson strut is an independent suspension system which is small and lightweight with very little unsprung mass. It has fewer total components compared to alternative suspension system and is fairly straight forward to assemble and repair (Chuan, 2005). Figure 1.1 shows the tramcar viewed from various angles.

(a)

(b)

(c)

(d)

Figure 1.1: The tramcar as viewed from various angles; (a) the front view of the tramcar, (b) the rear view of the tramcar, (c) the passenger seating in the tramcar, and (d) the interior view of the driver’s compartment

1.1 Objectives

The objectives of this project are:

i. To determine the acceleration response of the tramcar suspension
ii. To evaluate acceleration response in term of ride comfort level corresponding to available standards
iii. To suggest possible improvement in the comfort level in term of modifying the suspension parameters

1.2 Scope of the Project

The scopes of this study are:

i. The study on the tramcar built by UTM.
ii. The study focuses only on passive suspension system.
iii. The study will be evaluating the acceleration response of the tramcar in analysing the ride comfort level of passenger in the tramcar.
iv. Only ride analysis is performed and the vehicle handling analysis is neglected.
v. MATLAB Simulink would be used in performing the numerical analysis on the suspension system.
vi. The ride comfort analysis of the tramcar would be based on available benchmarks, either from standards such as ISO standards or from research findings by various researches.
vii. The suggestion for improvement would be by modifying suspension parameters.

1.3 Research Methodology

The research methodology flowchart for this project is shown in Figure 1.2. The proposed tasks to be performed to achieve the objective of the study and in compliance with the scope of the study are as outlined below:

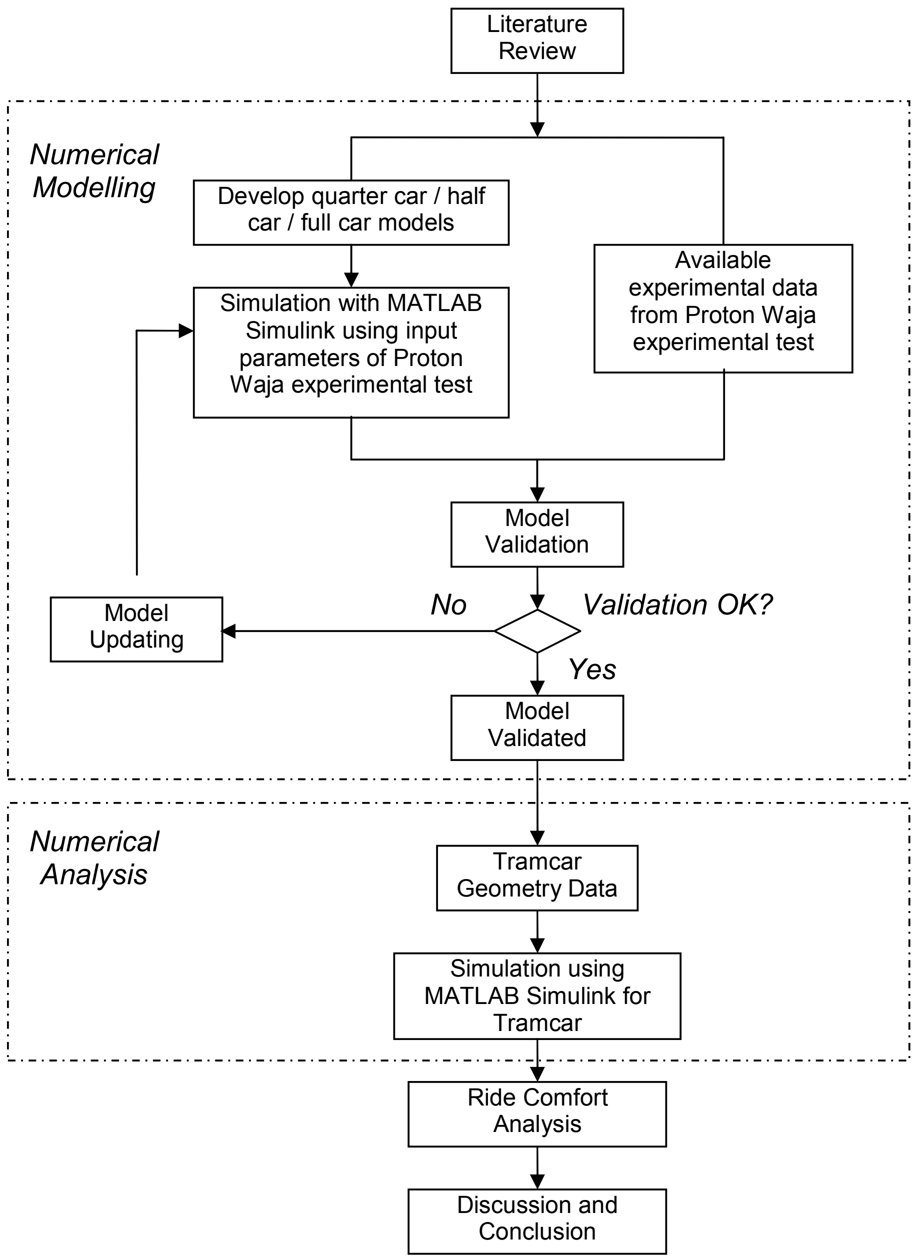

Figure 1.2: Research methodology flow-chart

1.3.1 Literature Review

The purpose of literature review is twofold; to get the theories and background information as the foundation of the study, and to get to know the past studies that have been done. The background information is gathered mostly from text books and reference books. The past studies are reviewed from technical papers. Internet sources were also reviewed. The standards will also be reviewed as the benchmark values for the judgement and evaluation to be made later on.

1.3.2 Numerical Modelling

The quarter car, half car, and full car models are going to be developed as the dynamic models for the numerical analysis. The mathematical model would be derived for each suspension model. From the mathematical models, numerical simulation will be performed using MATLAB Simulink. The input parameters would be the geometry data and the tramcar properties; the body properties, the vehicle estimated weight, and the suspension properties. The output parameters would be the displacement and acceleration response.

1.3.3 Model Validation

The model developed would be validated using available experimental results data obtained from literature. Using the same input parameters as used in the literature, the numerical simulation was executed using the numerical modal derived. The results of the output parameters from the simulation would be compared to that of the literature. The model would be validated given that the simulation results show a similar profile to that of the available experimental results.

1.3.4 Model Updating

With the experimental output data as reference, this step would be performed if there is no correlation between the simulation output data and the experimental output data.

1.3.5 Collecting the Geometry Data and Tramcar Properties

The geometry of the tramcar is to be measured directly in the reference vehicle real structure. It will be carried out using measurement instruments. For other tramcar properties that need to be determined using experimental techniques, such as determining the mass or the centre of gravity of the tramcar, the corresponding experimental testing would be performed.

1.3.6 Numerical Simulation

With the numerical model already validated, it would be used for the numerical simulation to obtain the output parameters for the tramcar. The input parameters would be from the tramcar geometry data and properties. The output of the simulation would be the dynamic response of the suspension system of the tramcar.

1.3.7 Ride Comfort Evaluation

The output data, namely the acceleration response, will be evaluated in comparison with available standards in judging whether the comfort level of the tramcar is within the benchmark comfort level or not. Ride comfort will also be evaluated by evaluating other output parameters, such as pitch rate and roll rate, given that the benchmark for those parameters is available.

1.3.8 Suggestion of Improvement

Some suggestions with regard to the suspension parameters will be made in the effort to increase the comfort level of the tramcar. Numerical simulation will be performed using the verified numerical model to illustrate the improvement that would be achieved with the implementation of the suggestions made.

1.4 Outline

Chapter 2 presents the literature review of related past studies. A number of related literatures will be reviewed and discussed. Chapter 3 presents the background theories relating to vehicle suspension. It discusses on the necessary background information; related definition and terminologies, suspension classifications and types, suspension components, ride quality aspects, role of vehicle suspension, suspension parameters and suspension system modelling and simulation. Chapter 4 presents the modelling and simulation of tramcar performed in this study. The numerical modelling process will be described, and the simulation analysis on tramcar suspension system will be presented. Chapter 5 presents the model validation and comparative study performed in achieving the objectives. The validation of the models developed in Chapter 4 will described. Comparative studies including ride quality evaluation with available standards and parametric studies will be presented. Discussion on the results and findings will also be presented. Finally chapter 6 summarises and conclude the study and provides recommendations for future works.