SIMULATION STUDY ON TRANSVERSE VIBRATION FOR AUTOMOTIVE ABSORBER

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MASTER OF MECHANICAL ENGINEERING (AUTOMOTIVE)

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**A thesis submitted
in fulfillment of the requirements for the degree of Master of Engineering
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2017

DECLARATION

I declare that this thesis entitled “Simulation Study On Transverse Vibration For Automotive Absorber” 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	:	NOR SHAZWAN AZRUL BIN NORAZNI
Date	:	6 JANUARY 2016

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Engineering in Mechanical Engineering (Automotive).

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Supervisor Name	:	DR. MOHD AZLI BIN SALIM
Date	:	6 JANUARY 2016

DEDICATION

To my beloved mother and father

ABSTRACT

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two parts. In addition, suspension systems are used for keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations. However, most of existing works on the suspension system especially the mathematical modelling models considers only the performance due to longitudinal direction. In order to realize the limitations of conventional suspensions in terms of shock absorption and vibration isolation along the longitudinal direction, therefore, transmissibility analysis of automotive absorber in transverse direction will be helpful to make a better understanding the behaviour of suspension system. The main objective of this study is therefore to modified existing mathematical model of automotive suspension to characterize the transmissibility performance that called transverse vibration model. Mathematical models for transmissibility are developed by using two different approaches: (i) lumped mass model and (ii) finite rod model. The first approach uses assumption of massless suspension absorber where the systems are simply modelled by using spring and damper elements. The second approach employs impedance technique derived from wave propagation across a finite rod model. In this approach, the internal resonance was predicted. It found that the wave effect in the distributed parameter suspension absorber have the potential to reduce the performance of the vibration absorber. The transmissibility for a wave effect for the transverse vibration model has a peak at a natural frequency and it is close to the fundamental resonance. Furthermore, the finding also revealed that transmissibility for the wave effect in the transverse vibration model is greater at higher frequency range. The mathematical model developed in this study proved capable of representing the transmissibility behavior of the transverse vibration model without the need to use physical test such as experimental testing. Last but not least, the parametric study also discussed in this thesis.

ABSTRAK

Sistem gantungan ialah istilah yang diberikan kepada sistem spring, penyerap hentak dan sambungan mekanikal yang menghubungkan kenderan dengan rodanya dan membolehkan gerakan relatif antara kedua-dua bahagian. Di samping itu, sistem gantungan yang digunakan juga memberikan penumpang pengasingan yang munasabah dan selesa dari bunyi bising jalan, bonggol dan getaran. Walau bagaimanapun, kebanyakan kerja-kerja sedia ada pada sistem gantungan terutama pemodelan matematik hanya mengkaji prestasi sistem gantungan pada arah menegak sahaja. Bagi meyedari had system gantungan konvensional dari segi penyerapan kejutan dan pengasingan getaran sepanjang arah membujur, oleh itu getaran dan analisis kebolehpindahan sistem gantungan automotif dalam arah melintang akan membantu untuk memahami tingkah laku sistem penggantungan dengan lebih baik. Oleh itu, objektif utama kajian ini adalah untuk ubahsuai model matematik system gantungan yang sedia ada penggantungan automotif untuk mencirikan prestasi kebolehpindahan yang dipanggil model getaran melintang. Model matematik untuk kebolehpindahan dibangunkan dengan menggunakan dua pendekatan yang berbeza: (i) sistem parameter tergumpal dan (ii) model getaran melintang. Pendekatan pertama menggunakan andaian penyerap penggantungan tanpa jisim di mana sistem tersebut hanya dimodelkan dengan menggunakan spring dan peredam. Pendekatan kedua menggunakan teknik galangan berasal dari perambatan gelombang seluruh rod. Dalam pendekatan ini, resonans dalaman dapat diramalkan. Ianya mendapati bahawa kesan gelombang dalam parameter penggantungan penyerap mempunyai potensi untuk mengurangkan prestasi penyerap getaran oleh sistem gantungan. Kebolehpindahan kesan gelombang untuk model getaran melintang mempunyai puncak pada frekuensi semula jadi dan ia terletak berhampiran dengan resonans asas. Tambahan pula, dapatan juga menunjukkan bahawa kebolehpindahan untuk kesan gelombang dalam model getaran melintang adalah lebih besar pada julat frekuensi yang lebih tinggi. Model matematik yang dibangunkan dalam kajian ini juga membuktikan kebolehan untuk menunjukkan tingkah laku kebolehpindahan model getaran melintang tanpa perlu menggunakan ujian fizikal seperti ujian eksperimen. Akhir sekali, analisis parameter turut dibincangkan dalam kajian ini.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SYMBOLS

m	Mass
c	Damping constant
k	Stiffness constant
λ	Eigen frequency
ω	Frequency at harmonic motion
σ	Normalized damping coefficient
x	Displacement
$\dot{x}$	Velocity
$\ddot{x}$	Acceleration
f_t , F_t	Transmitted force
f_e , F_e	Excitation force
X	Complex amplitude at the displacement
A , B , C , D	Complex wave amplitude
E	Young's Modulus
ρ	Density
η	Damping loss factor
Z_{11}, Z_{12}, Z_{21}, Z_{22}	Localized impedance
κ	Longitudinal rigidity
S	Cross sectional area
L	Length
M_e	Bending moment
Δx	Partial displacement
$\Delta\theta$	Rotation angle
I	Second moment of area
k_b	Bending wavenumber

τ_e	Shear force
T_F	Transmissibility force
ω_n	Natural frequency
ω / ω_n	Normalized frequency
D	Diameter
A	Area
r	Radius
G	Shear modulus
M	Working mass
M	Mass matrix
C	Damping matrix
K	Stiffness matrix
$\tilde{X}$	Vector of complex displacement amplitude
Z	Impedance matrix
F_1, F_2, F_3	Internal force

CHAPTER 1

INTRODUCTION

1.1 Research Background

An automobile is made up of many components that include with suspension, engine and its components which represent the many subsystems in a multi-degree of freedom. Apart from that, it is important to ensure the journey is safe and comfortable. This could be done by the car suspension system in order to keep the car in control while weakening the unpleasant shock or vibration due to road irregularities. Suspension system has been widely used as an absorber to suppress the level of vibration where combination of several components was used which is spring and damper element and located between tyre and vehicle body.

It is also designed to be very stiff for vertical load, so that it can carry the heavy weight of the vehicle mass. The spring and damper element are mainly configured in a vertical direction, although a small side-view inclination angle may exist between the vertical direction and the spring-damper strut axis (Emmanuel et. al., 2012). This type of construction and configuration has remained substantially unchanged for the past century. Such a design is actually a one dimensional configuration because it generally provides isolation mainly in the vertical direction to attenuate shock forces and disturbances (Truck et. al., 2009). The traditional engineering practice of designing a spring and a damper of a suspension system shown in Figure 1.1 and has been a compromise from its very inception in the early 1900's.

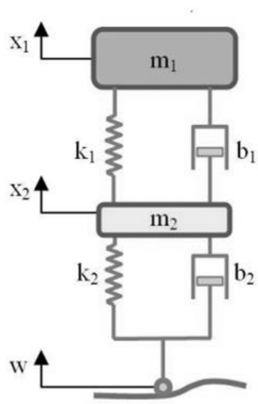

Figure 1.1: Schematic diagram of conventional suspension system.

Excitation of vehicle vibration arises mainly due to road disturbance, wheel non-uniformity, and unbalanced powertrain (Cole et. al., 2001). In many situations, road disturbance can impose contact force on a tire in different direction rather than merely the vertical one (Sharp et. al., 1998). Forsen et al. (1998) measured the lateral and longitudinal wheel force variations could be factor for vibration occurred in many direction. These forces are transferred to the body via a path "tire-suspension-chassis" and can induce vibrations in more than one direction. Multi-directional force variations result in vibration and shock that cannot be attenuated effectively by the conventional suspension system as these do not have elastic elements in non vertical direction.

Moreover, increasing in vibration on the components of suspension system in multi-directional force can change distribution of stress due to present of bending moment force. Hence, these unpleasant vibration and force condition will reduce life time by creating physical damage due to stress (Truck et. al., 2009). However, it appears to be lack of discussion regarding to analysis in multi-direction which include of longitudinal force, lateral force and bending moment. In order to realize the limitations of conventional suspension, therefore, the answer to this phenomenon seems to be found only in the development of an analysis model of suspension absorber in multi-direction which named as transverse vibration. Figure 1.2 shows the general modified model subjected to longitudinal excitation and orientation of moment which known as transverse vibration model.

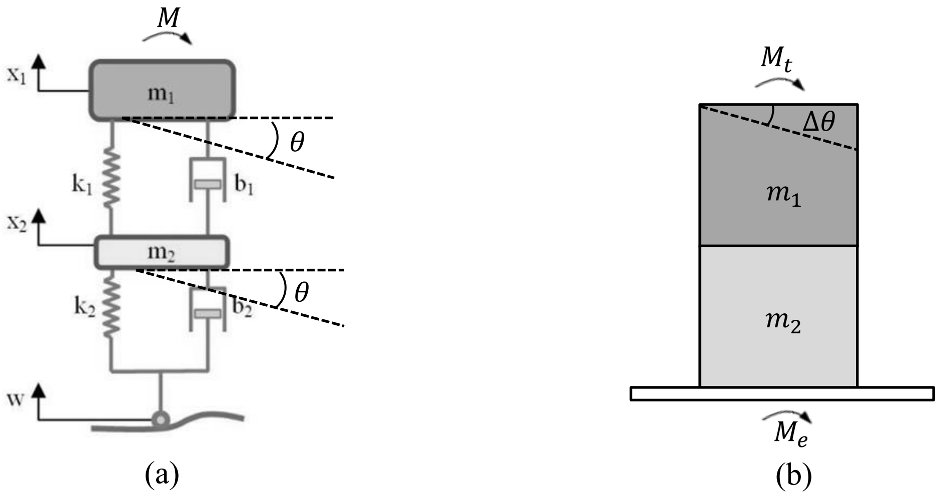

Figure 1.2: Vibration model in transverse direction (a) Mass spring damping system (b) Finite rod system.

In this study, wave propagation method are used for develop new mathematical modelling for transmissibility analysis of automotive absorber in transverse direction. The modified mathematical model is known as transverse mathematical model and it is capable to block vibration energy from longitudinal and transverse direction. The mathematical modeling is developed and finally the impedance matrix can be used to predict the transmissibility of the suspension absorber when the excitation force and moment force applied to the isolator. All of the model development and also transmissibility results are discussed in next section.

1.2 Problem Statement

Most of the existing works on the suspension system analysis, especially the mathematical models, only consider the vertical force and vertical excitation. The existing suspension analysis considers only the motion in the longitudinal direction, which dealing with longitudinal force from the road roughness. However, force excitation can also come from a non-vertical direction such as lateral direction or bending moment. In addition, the existing suspension absorber model, in which the mass of the absorber is ignored, offers a good prediction tool and provides design guideline at relatively low frequencies. At higher frequencies, the predictions based on the massless absorber model may be wrong and misleading. The distributed mass, stiffness and damping are introduced internal resonances or wave effects, in the absorber. This study therefore proposes to study the performance of the suspension system that subjected to such force where it called as transverse vibration. It is expected that the outcome of the study will contribute to the characterization of the existing suspension absorber performance and also the effect of resonance on transmissibility behaviour subjected to transverse vibration. As the suspension system in this study is to act as an absorber in the transverse direction, therefore it is conveniently called as transverse vibration model which is used in this thesis.

1.3 Research Hypothesis

This study is expected that the mathematical model technique can be used for finding approximate solution to transverse vibration problems for the suspension system. This method used for develop suspension model and simulate the transmissibility performance in transverse vibration. Another working theory raised in this research is that the entire suspension system can be modified into finite rod system in order to solve the vibration problem in transverse direction. In addition, another possible hypothesis can be made is the transverse vibration will be effected on transmissibility behaviour on automotive absorber where the effect of resonance on transmissibility can significantly observed.

1.4 Objective

The main goal of this research is to study the behaviour of transmissibility of automotive absorber in transverse direction. In order to fullfill this aim, the governing equation of automotive absorber had been developed using wave propagation method. Hence, the following goals can be considered as main objective of this study.

i. To modify existing mathematical model of automotive suspension system.
ii. To evaluate the transverse transmissibility performance in automotive suspension system.
iii. To perform parametric studies in order to examine the vibration behaviour in term of transmissibility.

1.5 Scope and Limitation

The research is subjected to the following scope and limitations:

i. The transverse vibration model are presumes as a finite rod model.
ii. The transmissibility characteristics only focus on the longitudinal direction and orientation of moment.

1.6 General Methodology

This study is initiated by reviewing all related literatures, particularly those providing study of suspension system, vibration in transverse direction and wave propagation method. Two methods are adopted in this study, which are briefly explained in