



# **SIMULATION STUDY ON TRANSVERSE VIBRATION FOR AUTOMOTIVE ABSORBER**

**NOR SHAZWAN AZRUL BIN NORAZNI**

**MASTER OF MECHANICAL ENGINEERING  
(AUTOMOTIVE)**

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**NOR SHAZWAN AZRUL BIN NORAZNI**

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in fulfillment of the requirements for the degree of Master of Engineering  
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## 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).

Signature : .....

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 kenderaan 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

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>vi</b>
<b>LIST OF FIGURES</b>	<b>vii</b>
<b>LIST OF APPENDICES</b>	<b>xi</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xii</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Research Background	1
1.2 Problem Statement	4
1.3 Research Hypothesis	4
1.4 Objective	5
1.5 Scope and Limitation	5
1.6 General Methodology	5
1.5 Thesis Outline	7
<b>2. LITERATURE REVIEW</b>	<b>9</b>
2.1 Introduction	9
2.2 Development of Suspension System	10
2.3 Description of Suspension System	12
2.4 Suspension Vibration Model	15
2.5 Ride Dynamic of Suspension System	17
2.5.1 Excitation Source of Road Roughness	18
2.5.2 Vehicle Response Properties	20
2.6 Vibration in Transverse Direction	22
2.6.1 Internal Resonance Effect	23
2.6.2 Internal Resonance Control	24
2.7 Investigation Into Suspension System Problem	25
2.7.1 Example of Matlab Simulink Approach	25
2.7.2 Example of Transfer Function Approach	26
2.7.3 Example of State Space Approach	28
2.8 Introduction of Suspension System Analysis	29
2.8.1 Vertical Vehicle Dynamic Response	29
2.8.2 Stability Response of Suspension System	30
2.8.3 Transmissibility of Suspension System	33
2.9 Critical Discussion	36
2.10 Summary	37
<b>3. MATHEMATICAL MODELLING</b>	<b>38</b>
3.1 Introduction	38
3.2 Mathematical Model of Lumped Parameter System	39
3.3 Mathematical Model of Wave Effect in Transverse Vibration	44

3.3.1	Derivation of Axial Vibration Using Wave Propagation Method	44
3.3.2	Derivation of Bending Moment Using Wave Propagation Method	47
3.4	Transmissibility of Transverse Vibration Model System	55
3.4.1	1 DOF of Transverse Vibration Model	55
3.4.2	2 DOF of Transverse Vibration Model	58
3.6	Summary	62
<b>4.</b>	<b>PRELIMINARY STUDY OF MATHEMATICAL MODELLING</b>	<b>63</b>
4.1	Introduction	63
4.2	Vehicle Specification	64
4.3	Preliminary Result on Lumped Parameter System	65
4.3.1	Displacement Response Behaviour	65
4.3.2	Stability Response Behaviour	68
4.3.3	Transmissibility of Lumped Parameter System	72
4.4	Preliminary Result on Transverse Vibration Model	76
4.4.1	Internal Resonance Behaviour	76
4.4.2	Transmissibility of Transverse Vibration Model	79
4.5	Result Comparison between Lumped Parameter System and Transverse Vibration Model	82
4.6	Summary	85
<b>5.</b>	<b>PARAMETRIC STUDIES</b>	<b>87</b>
5.1	Introduction	87
5.2	Parameter Range Value	88
5.3	Sprung Mass	89
5.4	Length of the Absorber	93
5.5	Stiffness	96
5.6	Damping Value	99
5.7	Summary	103
<b>6.</b>	<b>CONCLUSION AND FUTURE RESEARCH</b>	<b>104</b>
6.1	Introduction	104
6.2	Conclusion	104
6.3	Recommendation for future work	107
	<b>REFERENCES</b>	<b>108</b>
	<b>APPENDICES</b>	<b>117</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
4.1	Vehicle specification	64
4.2	Variable parameter of lumped system	65
4.3	Variable parameter for transverse vibration model	76
5.1	Parameter fraction value	88

## LIST OF FIGURES

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Schematic diagram of conventional suspension system	2
1.2	Vibration model in transverse direction	3
1.3	Flowchart of study	6
2.1	Suspension system relation	10
2.2	Suspension system and components	13
2.3	Types of independent suspension system	14
2.4	Full body of vibration model	15
2.5	Two common vibration models	16
2.6	Ride system relation	18
2.7	Typical spectral densities of road elevation profile	19
2.8	The elevation, velocity and acceleration PSDs at 50 Mph	19
2.9	Quarter car model	20
2.10	Effect of damping on suspension isolation behaviour	21
2.11	Quarter car Simulink model	26
2.12	Transfer function model	27
2.13	State space model	28
2.14	Vertical vehicle dynamics response	29
2.15	Stability response	31
2.16	Transmissibility of the single-degree-of-freedom when	35

	increasing the damping value	
3.1	Single and two-degree-of-freedom systems	39
3.2	Free body diagrams of single-degree-of-freedom system	40
3.3	Free body diagram of excited force for the single-degree-of-freedom system	41
3.4	Free body diagrams of two-degree-of-freedom system	42
3.5	Transmissibility of single-degree and two-degree-of-freedom system	43
3.6	Uniform finite rod undergoing longitudinal force	44
3.7	Uniform finite rod undergoing axial force	47
3.8	Partial displacement at uniform finite rod	47
3.9	Bending moments as uniform finite rod	48
3.10	Shear force at uniform finite rod	51
3.11	Absolute impedance for bending moment	55
3.12	Schematic diagram for one-degree-of-freedom of transverse vibration model	56
3.13	Transmissibility comparison between single-degree-of-freedom of lumped parameter and transverse vibration model	57
3.14	Schematic diagram for two-degree-of-freedom of transverse vibration model	58
3.15	One element in finite rod	59
3.16	Transmissibility comparison between two-degree-of-freedom of lumped parameter and transverse vibration model	61
4.1	Displacement result for two-degree-of-freedom of lumped parameter system	66

4.2	One cycle peak of two-degree-of-freedom of lumped parameter system	67
4.3	Stability result of two-degree-of-freedom of lumped parameter system	68
4.4	Rise time result of two-degree-of-freedom of lumped parameter system	79
4.5	Maximum overshoot of two-degree-of-freedom of lumped parameter system	70
4.6	Settling time of two-degree-of-freedom of lumped parameter system	71
4.7	Transmissibility result of two-degree-of-freedom of lumped parameter system	72
4.8	Transmissibility peak of two-degree-of-freedom of lumped parameter system	74
4.9	Transmissibility at high frequency region of two-degree-of-freedom of lumped parameter system	75
4.10	Absolute impedance of transverse wave	77
4.11	Transmissibility result of two-degree-of-freedom of transverse vibration model	79
4.12	Transmissibility peak of two-degree-of-freedom of transverse vibration model	80
4.13	Internal resonance of two-degree-of-freedom of transverse vibration model	82
4.14	Comparison between lumped parameter system and transverse vibration model	83

4.15	Maximum and minimum lines of internal resonance	84
5.1	Transmissibility result for sprung mass	90
5.2	Natural frequency analysis for sprung mass	91
5.3	Internal resonance analysis for sprung mass	92
5.4	Transmissibility result for dimension of the absorber	93
5.5	Natural frequency analysis for dimension of the absorber	94
5.6	Internal resonance analysis for dimension of the absorber	96
5.7	Transmissibility result for stiffness	97
5.8	Natural frequency analysis for stiffness	98
5.9	Internal resonance analysis for stiffness	99
5.10	Transmissibility result for damping value	100
5.11	Natural frequency analysis for damping value	101
5.12	Internal resonance analysis for damping value	102



## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt chart of research activities	118

## LIST OF SYMBOLS

$m$	Mass
$c$	Damping constant
$k$	Stiffness constant
$\lambda$	Eigen frequency
$\omega$	Frequency at harmonic motion
$\sigma$	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
$\rho$	Density
$\eta$	Damping loss factor
$Z_{11}, Z_{12}, Z_{21}, Z_{22}$	Localized impedance
$\kappa$	Longitudinal rigidity
$S$	Cross sectional area
$L$	Length
$M_e$	Bending moment
$\Delta x$	Partial displacement
$\Delta \theta$	Rotation angle
$I$	Second moment of area
$k_b$	Bending wavenumber

$\tau_e$	Shear force
$T_F$	Transmissibility force
$\omega_n$	Natural frequency
$\omega / \omega_n$	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

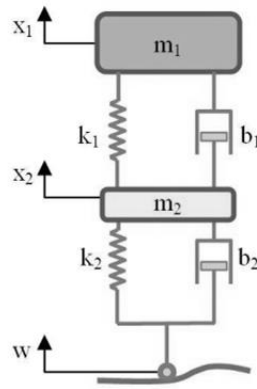
# CHAPTER 1

## 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.

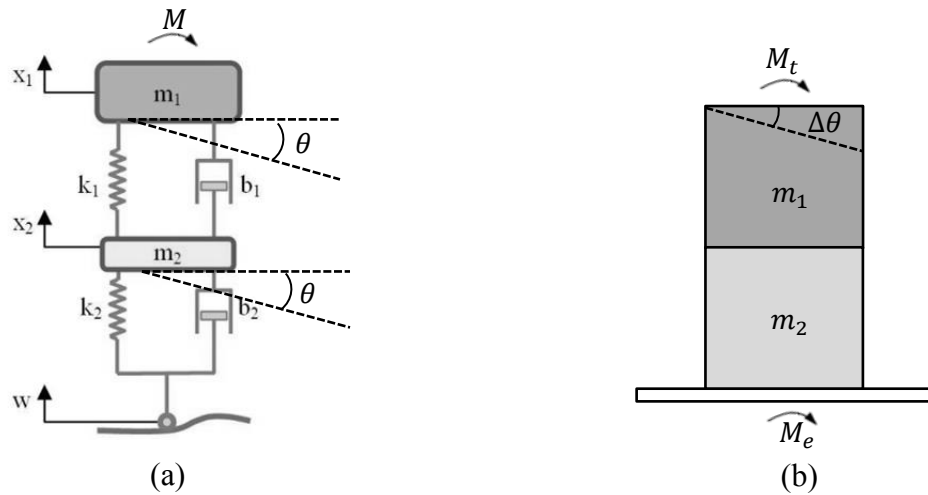


**Figure 1.1:** Schematic diagram of conventional suspension system.

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