VIBRATION INVESTIGATION OF PASSENGER CAR REAR SUSPENSION SYSTEM UNDER VARIOUS ROAD CONDITION AND DRIVING MANEUVER

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Suspension system plays an important role in the performance of a vehicle, especially vehicle handling and ride comfort. The objective of this project is to analyze the results in vibration of passenger car rear suspension system under various road conditions and driving maneuver. Experimental analysis was performed on the passenger car rear suspension system. The data collected by DEWESoft software was analyzed by using time domain analysis. In time domain analysis, the acceleration response of rear unsprung mass and suspension travel were determined by using post-processing method in Flexpro software. The maximum root mean square (r.m.s) acceleration of the unsprung mass was determined by using statistical analysis. In frequency domain analysis, the data was analyzed by using Fourier Spectral Analysis. The peak value of r.m.s amplitude of the unsprung mass acceleration was determined by using statistical analysis. The results were then evaluated by comparing them with different vehicle speed, road conditions and driving maneuver. From the results, it shows that the r.m.s acceleration of rear unsprung mass is increase as the vehicle speed increase, due to the excitation from the engine speed. The highest vehicle speed also produced response peaks at frequency range of 50 – 100 Hz and 200 – 250 Hz. The results also indicate that the bump road surface gives higher excitation to rear unsprung mass based on r.m.s acceleration value. Unpaved road surfaces give higher response peak in frequency range of 50 – 100 Hz. Next, the results obtained shows that constant speed at constant radius cornering maneuver gives higher r.m.s acceleration value and higher response peak to rear unsprung mass.

ABSTRAK

Sistem suspensi memainkan peranan penting dalam prestasi sesebuah kenderaan, terutamanya pengendalian kenderaan dan keselesaan. Objektif projek ini adalah untuk menganalisis hasil dalam getaran pada sistem suspensi belakang kereta dalam pelbagai keadaan jalan dan cara pemanduan. Analisis eksperimen telah dilakukan pada sistem suspensi belakang kereta. Data yang dikumpul oleh perisian DEWESoft dianalisis dengan menggunakan analisis domain masa. Dalam analisis domain masa, respon pecutan pada jisim sistem suspensi belakang dan pergerakan pegas pada sistem suspensi belakang ditentukan dengan menggunakan kaedah pemprosesan pasca di dalam perisian Flexpro. Nilai maksima punca kuasa dua pecutan pada jisim sistem suspensi belakang ditentukan dengan menggunakan analisis statistik. Dalam analisis frekuensi domain, seterusnya data dianalisis dengan menggunakan analisis Spektral Fourier. Nilai puncak amplitud punca kuasa dua pecutan jisim sistem suspensi belakang kereta ditentukan dengan menggunakan analisis statistik. Hasil analisis kemudian dinilai dengan membandingkan kesemuanya dengan kelajuan kenderaan yang berbeza, keadaan jalan dan cara pemanduan. Daripada hasil analisis, ia menunjukkan bahawa punca kuasa dua pecutan pada jisim sistem suspensi belakang bertambah sebagaimana halaju kenderaan bertambah, disebabkan oleh rangsangan daripada kelajuan enjin. Halaju kenderaan yang tertinggi juga menghasilkan puncak respon pada frekuensi di antara 50 – 100 Hz dan 200 – 250 Hz. Hasil itu juga menunjukkan yang jalan yang berbonggol memberikan rangsangan yang tinggi kepada jisim belakang sistem suspensi belakang berdasarkan nilai punca kuasa dua pecutan. Jalan yang tidak berturap memberikan puncak respon yang tertinggi dalam frekuensi 50 – 100 Hz. Seterusnya, hasil analisis yang diperoleh menunjukkan bahawa halaju yang malar pada cara pemanduan di bulatan memberikan nilai punca kuasa dua pecutan yang tinggi dan puncak respon yang tinggi kepada jisim belakang sistem suspensi.

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LIST OF SYMBOLS

C	Pitch moment of inertia
C_s	Damping stiffness
F_v	Sprung weight
g	Acceleration of gravity
K_s	Spring stiffness
M_s	Sprung mass
M_u	Unsprung mass
u	Road profile input
x	Unsprung mass displacement
X	Longitudinal
y	Sprung mass displacement
Y	Lateral
y_{ra}	Displacement of road profile at front tire's vehicle
y_{rp}	Displacement of road profile at rear tire's vehicle
Z	Vertical
Z_G	Center of gravity displacement
Z_{ra}	Front unsprung mass displacement
Z_{rp}	Rear unsprung mass displacement
Z_{sa}	Body pitch displacement
Z_{sp}	Sprung mass displacement

LIST OF ABBREVIATIONS

2D	Two dimensional
CAN	Controller Area Network
DAS	Data acquisition system
DADS	Database Application Development System
DOF	Degree of freedom
FFT	Fast Fourier transform
GPS	Global Positioning System
ISO	International Organization of Standardization
M/T	Manual transmission
RMS	Root mean square
SAE	Society of Automotive Engineers

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

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 behavior (Persegium, 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 tradeoff between the two quantities of ride comfort and vehicle stability. A suspension may be optimized for handling performance, or it may be optimized 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, 2000; Tener, 2004). If a suspension is designed to optimize 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 optimize the comfort level, the vehicle will be comfortable, but may not be too stable during maneuvers.

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".

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.

1.2 PROBLEM STATEMENT

Suspension system design is a challenging task for the automobile designers in view of multiple control parameters, complex objectives and disturbances. The roles of a suspension system are to support the vehicle weight, to isolate the vehicle body from road disturbances, and to maintain the traction force between the tire and the road surface. For vehicle suspension system design, it is always challenging to maintain simultaneously a high standard of ride, handling, and body attitude control under all driving conditions. Because of that, nowadays many types of suspension system has been designed and developed for vehicles, in general known as passive suspension system, semi active suspension system and active suspension system.

Each of the type of suspension has different advantages and disadvantages. Passive vibration control involves an inherent compromise between low-frequency and high-frequency vibration isolation. Passive suspension system consists of an energy dissipating element, which is damper and an energy-storing element, which is spring. Since these two elements cannot add energy to the system, this kind of suspension is called passive.

Passive suspension systems are subject to various tradeoffs when they are excited across a large frequency bandwidth. Compared with passive control, active and semi active control can improve the performance over the wide range of frequencies. The problems stem from the wide range of operating conditions created by varying road conditions, vehicle speed and driving maneuver. Based on this kind of investigation, the significant of the study is to address the characteristic and performance of the rear suspension system in various road conditions and driving maneuver.

1.3 PROJECT OBJECTIVES

The main objectives of this project:

(i) To perform on-road testing using test car data acquisition system and data collection for rear suspension system;

(ii) To analyze the results of vibration of passenger car rear suspension under various road condition and driving maneuver.

1.4 PROJECT SCOPES

This project is focusing on vibration analysis of passenger car rear suspension system under various road conditions and driving maneuver. This focus area is done based on the following aspects:

(i) Literature review on passive suspension system.

(ii) Experimental preparation on test car.

(iii) Data Acquisition System setup for measurement process purpose.

(iv) On-road test drive for rear suspension data collection.

(v) Vibration analysis based on variations of vehicle speed, road condition and driving maneuver.

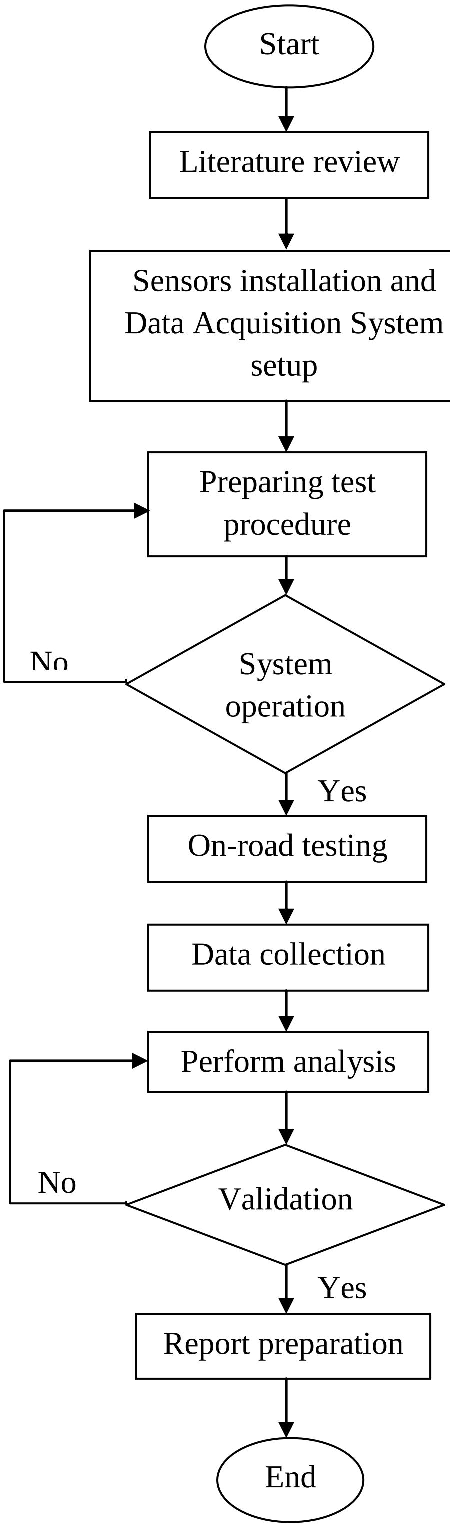
(vi) Data and analysis on acceleration response and suspension displacement of rear suspension system, and vehicle body acceleration response.

(vii) Final report preparation.

1.5 HYPOTHESIS

As the vehicle speed increase, the vibration of rear unsprung mass increase. Unpaved road surfaces give high excitation to rear unsprung mass because of the unevenness and roughness of the road surfaces.

1.6 PROJECT FLOWCHART



CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND THEORIES

2.1.1 Vehicle Axis System

The vehicle motions are defined with reference to a right-hand orthogonal coordinate system which originates at the centre of gravity (CG) and travels with the vehicle. By SAE convention, as shown in Figure 2.1, the coordinates are:

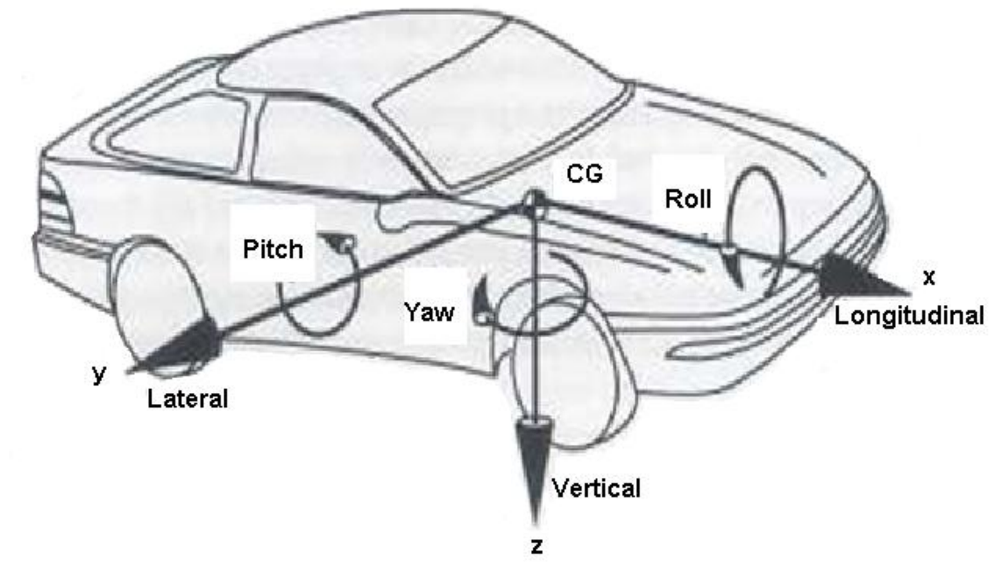


Figure 2.1: SAE vehicle axis system

Source: Gillespie (1992)

2.1.2 Terminologies

In this section, some terminologies related to the study will be listed out. The terminologies were taken from Vehicle Dynamics Terminology, SAE J670e.

(i) Degree of Freedom – the sum total of all ways in which the masses of the system can be independently displaced from their respective equilibrium positions.
(ii) Sprung Weight – all the weight which is supported by the suspension, including portions of the weight of the suspension.
(iii) Unsprung Weight – all weight which is not carried by the suspension system, but is supported directly by the tire or wheel, and considered to move with it.
(iv) Unsprung Mass – the equivalent masses which reproduce the inertia forces produced by the motions of the corresponding unsprung parts.
(v) Ride – the low frequency (up to 5Hz) of the sprung mass as a rigid body.
(vi) Vertical (bounce) – the translational component of ride vibration of the sprung mass in the direction of the vehicle z-axis.
(vii) Pitch – the angular component of the ride vibrations of the sprung mass about the vehicle y-axis.
(viii) Roll – the angular component of the ride vibrations of the sprung mass about the vehicle x-axis.

2.1.3 Role of Vehicle Suspension

From the understanding of ride quality aspects, one might hypothesize that the goal should be to eliminate all vibrations in a vehicle. Even though this will never be possible in a motor vehicle, it does give direction to development effort (Gillespie, 1992). The principle requirements of a vehicle suspension are (Gillespie, 1992):

(i) To provide good ride and handling performance – this require the suspension to have vertical compliance providing chassis isolation and ensuring that the wheels follow the road profile with very little tire load fluctuation.

(ii) To ensure that steering control is maintained during maneuvering – this requires the wheels to be maintained in the proper positional attitude with respect to the road surface.

(iii) To ensure that the vehicle responds favorably to control forces produced by the tires as a result of longitudinal braking and accelerating forces, lateral cornering forces and braking and accelerating torques – this requires the suspension geometry to be designed to resist squat, dive and roll of the vehicle body.

(iv) To provide isolation from high frequency vibration arising from tire excitation – this requires appropriate isolation in the suspension joints to prevent the transmission of 'road noise' to the vehicle body.

Thus, the primary functions of a suspension system are to (Gillespie, 1992):

(i) Provide vertical compliance so the wheels can follow the uneven road, isolating the chassis from roughness in the road.

(ii) Maintain the wheels in the proper steer and camber attitudes to the road surface.

(iii) React to the control forces produced by the tires – longitudinal (acceleration and braking) forces, lateral (cornering) forces, and braking and driving torques.

(iv) Resist roll of the chassis.

(v) Keep the tires in contact with the road with minimal load vibrations.

2.2 RIDE QUALITY

The vibration environment is one of the important criteria by which people judge the design and construction "quality" of the car. Being a judgment, it is subjective by nature, from which arises one of the greatest difficulties in developing objective engineering methods for dealing with ride as a performance mode of the vehicle. In understanding of the ride behavior, the overall dynamic system can be viewed as shown in Figure 2.2. The vehicle is a dynamic system, but only exhibits vibration in response to excitation inputs. The response properties determine the magnitude and direction of vibration imposed on the passenger compartment, and ultimately determines the passenger's perception of the vehicle. Thus, understanding ride involves the study of three main topics:

(i) Ride excitation sources
(ii) Basic mechanics of vehicle vibration response
(iii) Human perception and tolerance of vibrations

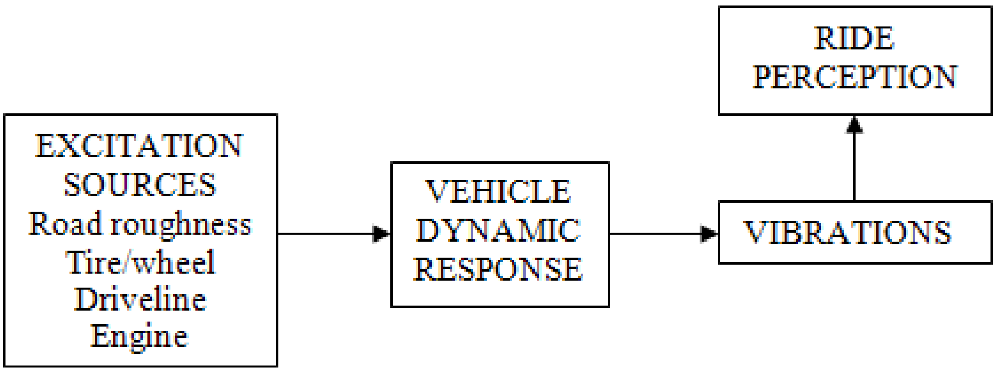


Figure 2.2: The ride dynamic system

Source: Gillespie (1992)

2.2.1 Ride Comfort Assessment

In continuation of what have been discussed on the perception of ride comfort, it would be obvious that there is the need for standards or benchmarks on suspension parameters related to ride comfort. As mentioned earlier, being a subjective evaluation, there would be no absolute benchmarks on ride comfort level (Gillespie, 1992). Here, some of the benchmarks proposed by various researchers will be listed.

Gillespie (1992) have presented a review of the vibration limits for human comfort from various researches that have been done since 1920s. The plots of RMS acceleration against frequency by various researchers are shown in Figure 2.3. David E. Goldman from Naval Medical research Institute have come up with subjective responses of the human to vibratory motion, in the form of displacement amplitude against vibration frequency graph as shown in Figure 2.4 (Gillespie,1992). The data are for short duration exposure (a few minutes) of the body standing or sitting on a vibrating support subjected to vertical oscillation.

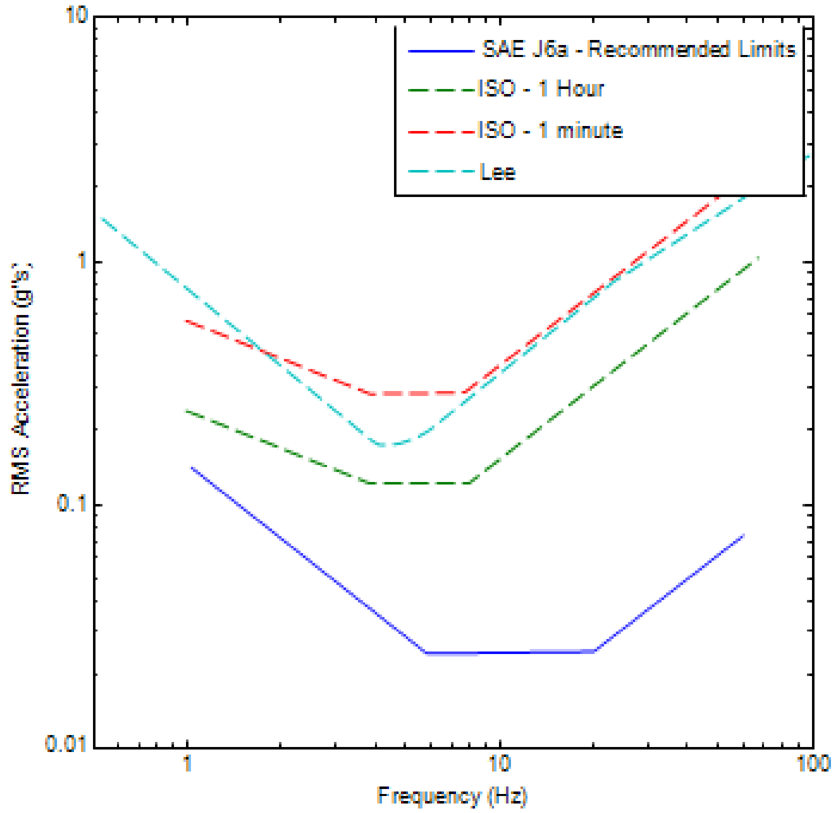


Figure 2.3: Human tolerance limits for vertical vibration

Source: Gillespie (1992)

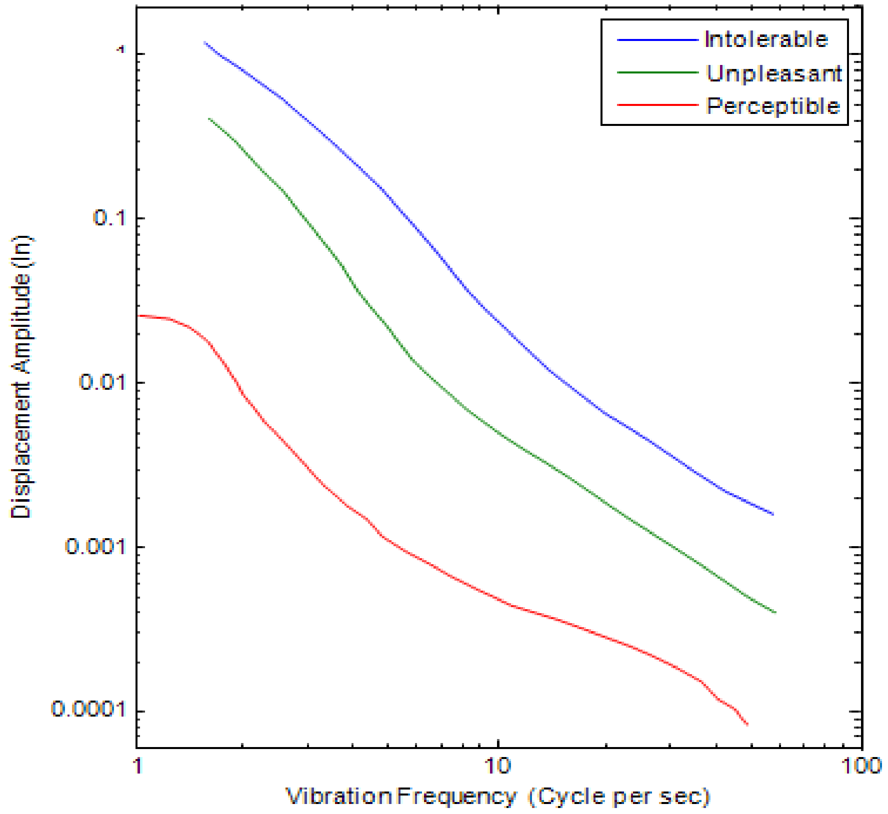


Figure 2.4: Subjective response of the human body to vibration mode

Source: Gillespie (1992)

R. N. Janeway from Janeway Engineering Co. has put forward a vertical vibration limits for passenger comfort, shown in Figure 2.5 in the form of displacement amplitude against vibration frequency graph (Gillespie, 1992). The three broken lines define the sensation thresholds, either 'strongly noticeable', 'uncomfortable', and 'very uncomfortable'. It was claimed that the recommended limit, represented by the unbroken line in the graph, should be well within the comfort range even for the most sensitive person. The recommended criterion consists of three simple relationships, each covering a portion of the frequency range, as shown in Table 2.1.