VIBRATION INVESTIGATION FOR PASSENGER CAR WITH DIFFERENT DAMPING CHARACTERISTIC ON CAR SUSPENSION SYSTEMS

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ABSTRACT

This thesis investigates the effect of vibration and vehicle body movements acting on the vehicle's wheel due to the different damping characteristics of suspension systems. Three different damping characteristics damper named Absorber A, Absorber B and Absorber C was installed on the suspension system of the Proton Persona which was used as a test car. This test car was equipped with accelerometers and wire potentiometer sensor on the front and rear suspensions, gyroscopic, Global Positioning System (GPS) and connect with DEWEsoft software as a data acquisition. To study the effect of three different damper characteristics on suspension system, the ride comfort analysis and car body movement analysis were used to analyze the result during experimental testing. There were 7 maneuver testing experiment were performed including acceleration, engine braking, steady-state braking, steady-state cornering, single-lane change, slalom and bump testing experiment. Based on the results, comparison between the suspension damper characteristics due to the driving maneuvers and car movement were made and their performance also were ranked. Absorber A was the hardest damper as compared to Absorber C and Absorber B according to the damping constant value. The result showed that the best performance for car movement made by Absorber A then followed by Absorber C and Absorber B, while the best performance for ride comfort analysis was made by Absorber B followed by Absorber C and A. Meanwhile Absorber A showed the lowest values of car body movement analysis and Absorber C showed the lowest values of suspension ride comfort analysis during acceleration, engine braking, steady-state braking and steady-state cornering tests. Absorber A was suitable for a flat road driving while Absorber C was suitable for a large road disturbance driving.

ABSTRAK

Tesis ini mengkaji kesan pergerakan tubuh getaran dan kenderaan yang bertindak pada roda kenderaan kerana ciri-ciri penyerap hentakan yang berbeza pada sistem penggantungan. Tiga ciri-ciri yang berbeza penyerap hentakan dinamakan Penyerap A, Penyerap B dan Penyerap C telah dipasang pada sistem penggantungan Proton Persona yang digunakan sebagai kereta ujian. Kereta ujian ini dilengkapi dengan meter pecutan dan wayar sensor upaya pada suspensi depan dan belakang, giroskop, Sistem Kedudukan Global (GPS) dan disambung dengan perisian DEWEsoft sebagai pemerolehan data. Untuk mengkaji kesan tiga penyerap hentakan yang mempunyai cirri-ciri berbeza pada sistem penggantungan, analisis keselesaan pemanduan dan analisis pergerakan badan kereta telah digunakan untuk menganalisis keputusan semasa ujian eksperimen. Terdapat 7 jenis ujian eksperimen dilakukan termasuk pecutan, brek enjin, brek keadaan mantap, memborong keadaan mantap, perubahan lorong tunggal, *slalom* dan benjolan eksperimen ujian. Berdasarkan keputusan, perbandingan di antara ciri-ciri penyerap hentakan penggantungan akibat jenis pemanduan dan pergerakan kereta dibuat dan prestasi mereka juga turut dinilai. Penyerap A adalah peredam yang paling keras berbanding Penyerap C dan Penyerap B mengikut nilai pemalar serapan hentakan. Hasilnya menunjukkan bahawa prestasi terbaik bagi pergerakan kereta yang dibuat oleh Penyerap A kemudian diikuti oleh Penyerap C dan Penyerap B. Manakala prestasi terbaik untuk analisis keselesaan pemanduan diberikan oleh Penyerap B, diikuti oleh Penyerap C dan A. Ini bermaksud, Penyerap A menunjukkan nilai-nilai analisis pergerakan badan kereta yang paling rendah. Manakala Penyerap C menunjukkan nilai terendah bagi penggantungan analisis keselesaan pemanduan semasa pecutan, enjin brek, brek keadaan mantap dan keadaan mantap memborong ujian. Penyerap A adalah paling sesuai untuk pemanduan jalan yang rata manakala Penyerap B adalah paling sesuai untuk pemanduan di jalan besar.

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LIST OF SYMBOLS

p	roll velocity
q	pitch velocity
r	yaw velocity
v	side velocity
w	normal velocity
a_w	RMS acceleration
long	longitude
lat	latitude
vert	vertical
s	second
km/h	kilometer per hour
rad/s	radian per second
m/s^2	meter per second square
g	gravity

LIST OF ABBREVIATIONS

ISO	International Organization for Standardization
BS	British standard
AAP	Average absorb power
CF	Cornering force
AAP	Average Absorbed Power
CG	Center of Gravity
USA	United State of America
NRMM	NATO Reference Mobility Model
WT	Weight transfer
WB	Weight balance
SAE	Society of Automotive Engineer
RMS	Root mean square
KYB	Kayaba
CW	Clockwise
CCW	Counter clockwise
EB	Engine Braking
SSB	Steady State Braking
SSC	Steady State Cornering
SLC	Single Lane Change
Acc	Acceleration
NATO	North Atlantic Treaty Organization

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The purpose of a vehicle is to transport people or cargo from one place to another. Embedded in this purpose in doing so, it shall be as little disturbance as possible of who or what is being carried. Suspension is a term which is specified for the system of springs, shock absorbers and linkages that connect a vehicle to its wheels. The vehicle suspension systems basically consist of wishbones, the spring, and the shock absorber to transmit and also filter all forces between body and road. The task of the spring is to carry the body-mass and to isolate the body from road disturbances and thus contributes to drive comfort. The suspension system is located between axles and the vehicle body or frame as shown in Figure 1.1. For safety purpose, stability, handling and performance of a vehicle depend on many factors. One of the most important aspects of these characteristics is the design of the damper. The characteristics of dampers are normally a correlation between ride comforts and handling.

The suspension need to focus on support the weight of the vehicle, absorb road shocks and cushion the passenger against those shocks, provide steering control during severe braking. Notionally, if a road were perfectly flat, with no abnormality, suspension would not be necessary. Unfortunately, roads are far from flat. Without suspension, a motor vehicle travelling at today’s speeds would not only be uncomfortable, it would be virtually

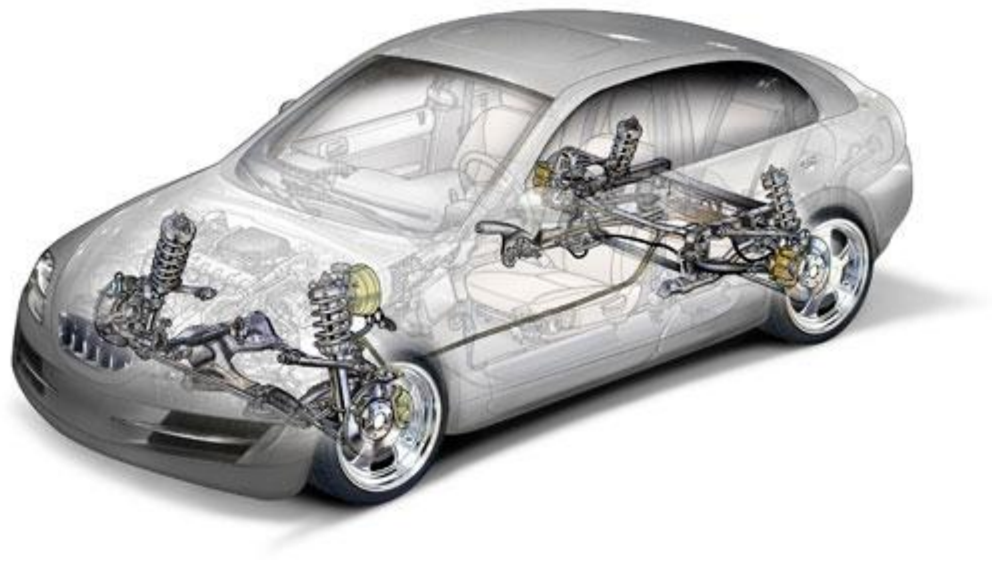

Figure 1.1: The location of car suspension system on a car

Source: blog.carlist.my (1998)

to have used elastic wooden poles to reduce the affects of wheel shock. Leaf springs in one form or another have been used since the Romans suspended a two wheeled vehicle called a Pilentum on elastic wooden poles. After that, new inventor carriage designs included rudimentary leaf suspension systems. All through the history, leaf springs would dominate as the primary suspension design until quite recently (Staniforth, 2006). Leaf springs presented the profit of simplicity in design and relatively economical cost. By merely adding leaves or changing the shape of the spring, it could be made to support varying weights. As a result, major changes primarily tended to revolved around the use of better quality materials and making improvement in design modifications.

1.2 PROBLEM STATEMENT

Each of the suspension has the advantage and disadvantage. For example the suspension with the damping characteristic too hard or stiffer, it is not good because it cannot isolate the vehicle body from road disturbance, but when the damping characteristic of the suspension is too soft, it will make the vehicles a large vibration and can make the driving not comfortable. Based on this kind of investigation, the significant of the study is to investigate how the characteristic of the damping on car suspension system can result the vibration to the car.

1.3 PROJECT OBJECTIVES

The main objective of this project is to investigate the vibration effect of different damping characteristics on car suspension system.

1.4 PROJECT SCOPES

This project has to focus on few scopes in order to achieve the objectives:

(i) Literature review on damper and vibration on the suspension system.
(ii) Preparations on the procedures for installation on displacement sensor and pre-testing.
(iii) Run the experiment based on the procedures.
(iv) Analyzed the results gained on the car suspension relates to the different damping characteristics and driving condition.
(v) Discuss and conclude the project in a final report.

1.5 PROJECT FLOW CHART

Figure 1.2 shows the project flowchart for this FYP. On the first week, we have done a meeting with the supervisor and we have discussed about the project title. My supervisor has asked me to find the related articles, journal and other for the references along this FYP. Then based on the literature study, writing the project proposal, on the mid of the semester the midterm presentation, and lastly the final presentation on 15^{th} week of the semester. After that the complete thesis need to submit on the 16^{th} week at the end of the semester.

1.6 SUMMARY

The project background, objective, problem statement, and project scope was very important in order to guide me follow the project cover. While the project flowchart was guide me to complete the work at the time given.

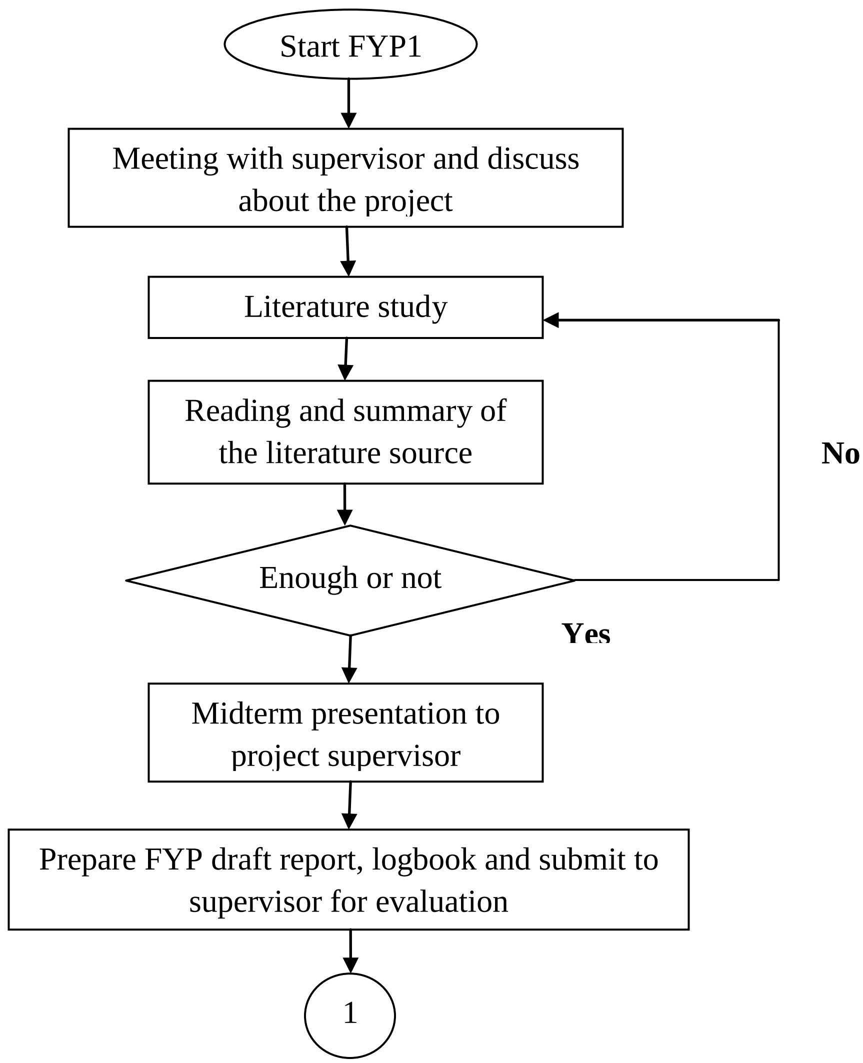

Figure 1.2: Project flow chart

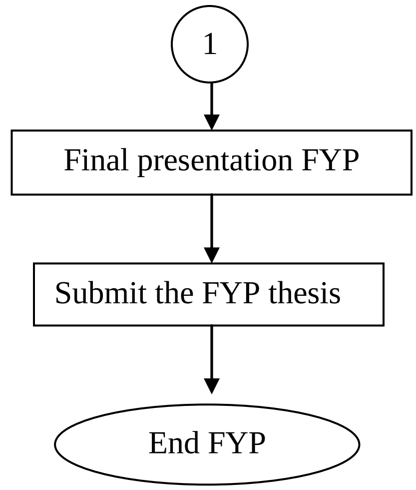

Figure 1.2(continued): Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research effort to damping system, vehicles or car suspension, vibration and the relation between them. A review of other relevant research studies is also provided. Substantial literature has been studied on the car damper characteristics. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope of the present research effort.

2.2 CAR SUSPENSION AND DAMPING SYSTEM

2.21 Vehicles

The automobile industry is under ever more pressure to bring new models to market quickly, give innovation on reducing costs, reducing fuel consumptions and reducing the environmental pollutions. Figure 2.1 shows the various types of vehicles nowadays with different sizes and function. The most important purpose of a vehicle is to transport people or cargo from one place to another (Bastow *et al.*, 2004). Implicit in that statement is that in doing so, there shall be as little disturbance as possible of who or

Figure 2.1: Various type of vehicles nowadays

Source: dubaistoragecompany.blogspot.com (2010)

what is being carried. If the load is inanimate, the less the disturbance and the less the need for special packaging. If the load is animate, then the longer the journey can be without fatigue, the better the condition after the journey. In the case of the driver of the vehicle, the less the fatigue, the greater the levels of concentration that can be maintained and the safer the driver's performance, especially toward the end of the journey.

2.22 History of Suspension System

Automobiles were initially developed as self-propelled versions of horse drawn vehicles (Halsey and William, 1979). However, horse drawn vehicles had been designed for relatively slow speeds and their suspension was not well suited to the higher speeds permitted by the internal combustion engine.

In 1901 Mors of Germany first fitted an automobile with shock absorbers. With the advantage of a dampened suspension system on his 'Mors Machine', Henri Fournier won the prestigious Paris-to-Berlin race on the 20th of June 1901. Fournier's superior time was 11 hours 46 minutes 10 second, while the best competitor was Léonce Girardot in a Panhard with a time of 12 hours 15 minutes 40 second. (Pradko and Lee, 1996). In 1920, Leyland used torsion bars in a suspension system. In 1922, independent front suspension was pioneered on the Lancia Lambda and became more common in mass market cars from 1932 (Halsey and William, 1979).

2.3 VIBRATION

Any motion that repeats itself after an interval of time is called vibration or oscillation (Rao, 2004). The theory of vibration deals with the study of oscillatory motions of bodies and the forces associated with them. The vibration of a system involves the transfer of its potential energy to kinetic energy and kinetic energy to potential energy (Bastow *et al.*, 2004). In various land vehicles the isolation of the seated operator from vibration and shock is of consider importance. Exposure to whole-body vibration in the working environment may lead to fatigue in some case to injury.

2.4 THEORY

The word suspension is the term given to the system that contains spring, shock absorbers and linkages that connects a vehicle to wheels. Suspension system isolates the people or cargo from severe levels of vibration and shock induced by the road surface. This isolation from road-induced shock and vibration is very important to improve and increase the longevity and durability of the vehicles (Bastow *et al.*, 2004). Figure 2.2 show the suspension system in a vehicle body. The suspension basically includes the springs, damper and the wheel axle.

The suspension systems also enables the wheels to maintain contact with the road surface, assuring the stability and control of the vehicle because all the forces acting on the vehicle do so through the contact patches of the tires (Hasagasioglu, 2011). The suspension system is an important factor in determining the comfort of a car because the suspension system is the pivot between the wheels with the weight of the car

Figure 2.2: Suspension system on the vehicle

Source: Larry Carley (2012)

and also serves to dampen shocks and engine sound. In other words, the job of a vehicles suspension is to maximize the friction between the tires and the road surface, to give the stability of handling the vehicles and to provide the comfort of the passengers (Els *et al.*, 2007). If the road is flat with no irregularities, the suspension maybe might not be possible. But the flat road can said to be impossible (Bastow *et al.*, 2004). It's means that the suspension was very important part in order to reduce the effect regarding to the flatness of the road surface. Figure 2.3 show the basic concept of a suspension system. The suspension basically main objective is to supporting the sprung mass and the unsprung mass.

A bump or subtle imperfections on the road surface causes the wheel to move up and down perpendicular to the road surface. In this situation, the vehicles can be loose handle and make the driving unsafe. At this time, the suspension can play its role that ensure the tires always contact with the road surface and maintain the control over the vehicle and drive it safely (Els *et al.*, 2007). The suspension is located at the wheels of the vehicles. So, the most important thing to consider while building a suspension

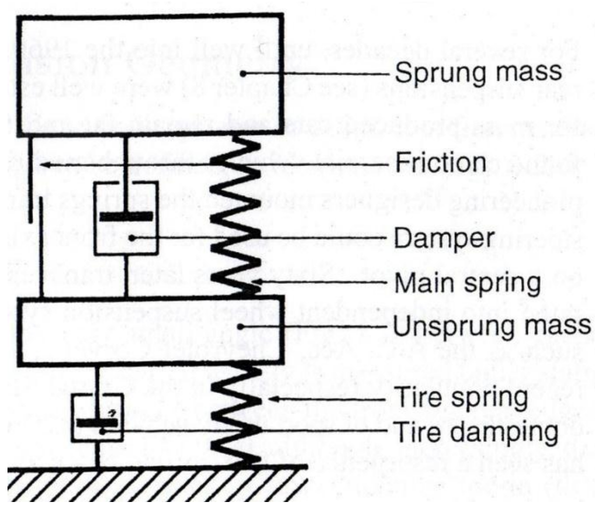

Figure 2.3: Basic elements of suspension system

Source: Bastow (2004)

system is the suspension is used to support a load from above such as the body of the vehicles, the loadings, the passengers and so on. The spring is what actually support the weight of the vehicle and will determine how the vehicle's weight changes when braking, acceleration and cornering.

2.41 Suspension Elements

When building a suspension, three most crucial elements must be considered. The first thing is flexibility (Bastow *et al.*, 2004). It is refers to designs of the suspension system that can adapt or giving the good respond to potential internal or external changes affecting its value delivery. Flexibility is given by a spring (on the suspension system) that distort and recovers (typically compress and expands) as the wheel traverses disturbances in the road surface. The second thing is damping which is essentially to restrain the body and wheel resonant bouncing motions. According to Singiresu (Singiresu, 2004) damping is defined as the mechanism by which the vibrational energy is gradually converted into heat or sound. Singiresu also assume the damper to have neither mass nor elasticity, and damping force exists only if there is relative velocity between the two ends of the dampers. And the third one is the location of the wheel (Bastow *et al.*, 2004).

2.42 The Principle of Suspension System

The vehicle suspension systems basically consist of wishbones, the spring, and the shock absorber to transmit and also filter all forces between body and road. The task of the spring is to carry the body-mass and to isolate the body from road disturbances and thus contributes to drive comfort. Table 2.1 discusses the suspension component, properties (composition and position) and its function.

The damper contributes to both driving safety and comfort. Its task is the damping of body and wheel oscillations, where the avoidance of wheel oscillations directly refers to drive safety, as a non-bouncing wheel is the condition for transferring road-contact forces. Considering the vertical dynamics and taking into account the vehicle's symmetry, a suspension can in a first step be reduced to the so-called quarter-car model as shown in Figure 2.4. Here, elements for modeling the Coulomb friction and an additional force resulting from active or semi-active components are added. The tire is typically modeled by a single spring.

`Now, the terms of driving safety and comfort are defined. Driving safety is the result of a harmonious suspension design in terms of wheel suspension, springing, steering and braking, and is reflected in an optimal dynamic behavior of the vehicle, whereas driving comfort results from keeping the physiological stress that the vehicle occupants are subjected to by vibrations, noise, and climatic conditions down to as low a level as possible. It is a significant factor in reducing the possibility of misactions in traffic (Worden *et al.*, 2008) and typically, the acceleration of the body. As an obvious quantity for the motion and vibration of the car body and the tire load variation as indicator for the road contact are used for determining quantitative values for driving comfort and safety, respectively.