ANALYSIS OF SEMIACTIVE CONTROL POLICIES FOR PASSENGER VEHICLES

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ABSTRACT

Comprehensive comparison on quarter-car, half-car and full-car models were conducted to analyze the effect of using semiactive control policies, namely skyhook, groundhook and hybrid controls, in improving ride quality of passenger vehicle. Sprung mass acceleration, suspension deflection and tire deflection responses were analyzed for measurements of ride quality, rattle-space and road holding, respectively. Analyses in frequency-domain transfer function, time-domain transient state and time-domain steady state were conducted on each of the models. Peak-to-peak values in both time-domain analyses and settling time and steady state values in the transient state were compared to passive system. Results show that hybrid control policy gives significant improvements in most responses while at the same time it does not compromise road holding ability of vehicle. Skyhook control generally improves sprung mass responses while at the same time increases unsprung mass responses. On the other hand, groundhook control generally improves unsprung mass responses at the expense of sprung mass responses. Groundhook control also found to take longer time to settle in transient state response. Further quantitative comparison of responses on all three models shows that quarter-car model is unable to accurately represent responses in full-car model. Half-car model gives reasonable representation of full-car model in some of the states. Root mean square analysis is further conducted on a H-car 2-DOF system and the results show good agreement to the previous work on Q-car 2-DOF. As expected, the response exhibit similar behavior of the skyhook control.

ملخص البحث

تمت المقارنة الشاملة على موديل ربع سيارة، نصف سيارة، وسيارة كاملة في الدراسة لتحليل تأثيراستخدام طرق السيطرة شبه النشطة، مثل التعليق الفضائي، التعليق الأرضي والسيطرة الهجينة، في تحسين نوعية جلوس الركاب في مركبات نقل الأشخاص. تعجيل الكتلة النابضة، وانعكاس إنحراف التعليق وردود أفعال إنحراف الإطارات، كلها تم تحليلها لقياسات نوعية الركوب، وفضاء الحشرجة، وتحمل الطريق، بالتتابع. التحليل في مجال ميدان التردد، ومجال وقت حالة التغيير، ومجال وقت الحالة الثابتة، كلها تم العمل عليها لكل موديل. قيم الذروة في كل من تحليل تعميم الوقت ووقت الاستقرار وقيم الحالة المستقرة في حالة الحركة تم مقارنتها مع النظام السلبي. بينت النتائج بأنه طريقة السيطرة الهجينة تعطي تحسين ملحوظ في معظم ردود الأفعال بينما في نفس الوقت لم تعطي تسوية لقابلية تحمل الطريق للمركبة. بصورة عامة فإن مسيطر التعليق الفضائي قد حسّن ردود أفعال الكتلة النابضة بينما في نفس الوقت زاد ردود أفعال الكتلة غير النابضة. من جهة أخرى، فإن مسيطر التعليق الأرضي بصورة عامة قد حسّن ردود أفعال الكتلة غير النابضة على حساب ردود أفعال الكتلة النابضة. كما وجد أيضاً أن مسيطرالتعليق الأرضي بأخذ وقت أطول للاستقرار في رد فعل حالة الحركة. وأوضحت المقارنة الكمية لردود أفعال الموديلات الثلاثة أن موديل ربع مركبة كان غير قابلاً لتمثيل ردود الأفعال بصورة مضبوطة كما هو الحال في المركبة الكاملة. موديل نصف المركبة أعطى تمثيل معقول لموديل المركبة الكاملة في بعض الحالات. كما تم تحليل المعدل التربيعي الجذري على نظام نصف مركبة 2- دوف والنتائج أوضحت توافقاً مع النتائج السابقة على ربع مركبة 2- دوف. وكما متوقع، فإن ردود الأفعال أعطت نفس التصرف لمسيطر التعليق الفضائي.

APPROVAL PAGE

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Sany Izan Ihsan

Signature …………………………………… Date ……………………..

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Signature Date

To my beloved wife, Suriza Ahmad Zabidi,

My lovely children, Muhammad, Zubair, Muaz and Sofwan,

For their love and company

To my father, Ihsan Hj Awang and mother, Chong Kee Yin @ Aisah Abdullah

May Allah bless and grant upon them mercy

In this world and hereafter…

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure No. Page No.

LIST OF ABREVIATION

CG	Center of gravity
cpm	Cycle-per-minute
-DOF	Degree-of-freedom
ER	Electro-rheological
ERF	Electro-rheological fluid
F-car	Full-car
H-car	Half-car
ISO	International Organization for Standardization
LTI	Linear time invariant
MR	Magneto-rheological
MRF	Magneto-rheological fluid
m_s	Sprung mass
m_{us}	Unsprung mass
PSD	Power spectral density
PTP	Peak-to-Peak
Q-car	Quarter-car
RMS	Root mean square
SAE	Society of Automotive Engineers
t_s	Settling time

LIST OF SYMBOLS

ζ_s	Damping Ratio
r_k	Spring Ratio
ω_n	Natural Frequency

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

By definition, Ride Quality is degree to which the whole subjective experience (including the motion environment and associated factors) of a journey or ensemble of journeys by vehicle is perceived and rated as favorable or unfavorable by passengers or operators (International Organization for Standardization [ISO] 5805, 1997). Its primary concern is on sensation or feel of driver or passenger in the environment of a moving vehicle. In a simple word, ride is considered as comfort when the occupant is comfortable riding the vehicle. Vehicle ride quality is strongly related to the pitch and vertical motions of the vehicle.

Vehicles traveling at high speed usually experience a broad spectrum of vibrations. These vibrations are transmitted to passengers either by tactile, visual or aural paths (Gillespie, 1992). Ride is usually dealing with the tactile and visual vibrations, while the aural vibration is categorized as noise. Alternatively, spectrum of vibrations may be categorized by frequency range and specified as ride for frequency range of 0 to 25 Hz and noise between 25 to 20000 Hz.

Ride quality is affected by various designs and operating parameters in a highly complex manner, including high frequency vibrations, body booming, body roll and pitch motion, vertical motion by spring in the suspension system and frequency vibration transmitted from the road input excitations. Other factors include high frequency vibrations or noise induced by aerodynamic forces as well as the engine and driveline. Ride quality can also be influenced by vehicle interior design such as seat comfort, temperature, ventilation, location of features etc. Among these factors, the major source of vibration of a vehicle that affects ride quality is the road irregularities which are transferred to the passenger through the tires and suspension system.

Generally vibrations affecting ride quality can be categorized into two parts; low frequency vibrations and high frequency vibrations. The range differs from one researcher to another, but is generally agreed that the low frequency is less than around 25 Hz. High frequency vibrations may be excited by either impacts originating at the wheels and transmitted through the suspension, or alternating forces by unbalanced rotating masses in the engine (Janeway, 1948). This vibration may be eliminated by having proper cushioning of impact and accurate balancing of high speed rotating parts. However, low frequency vibrations, which mainly due to the road irregularities posed more significant effect on the ride quality of vehicle. This is due to it being close to the natural frequencies of vehicle. Generally the natural frequency of sprung mass (mass of the vehicle, excluding the tire and its components) is about 1 Hz, the natural frequency of unsprung mass (mass of the tire and its components) is between 8 to 10 Hz and there exist an intermediate natural frequency between 6 to 20 Hz (Janeway, 1948).

To eliminate this low frequency vibrations effect on passenger, there are several components of interest that become the focus of improvement; tire, suspension and passenger seat. Tire technology has come to its relative stagnant, as not much improvement can be made as far as ride quality is concerned. Limited improvements can be made on the seat but at the expense that the vehicle as a whole having to face the vibrations, which could cause some components failure. The focus of most researchers in this area is thus looking towards improving the suspension system in order to eliminate the vibrations. Several researchers have proposed the concept of active control system, which claimed to eliminate the inherent problem of passive suspension system – that is the conflicting parameters for ride and handling. However, this new system is by far still not free from any shortcomings.

1.2 RIDE QUALITY CRITERIA

Over the years, various researches were conducted to identify some generalized criteria in ride quality, which is commonly called as ride comfort criteria. Several approaches have been proposed. One of them is Janeway's comfort criterion, which is described in the *Ride and Vibration Data Manual J6a* of the Society of Automotive Engineers (SAE) (1965). Figure 1.1 defines the acceptable amplitude of vertical vibration as a function of frequency and it could be divided into three parts:

1. Frequency range of 1-6 Hz - peak jerk < 12.6 m/s^3 (496 $in./s^3$)
2. Frequency range of 6-20 Hz - peak acceleration < 0.33m/s^2 (13 $in./s^2$)
3. Frequency range of 20-60 Hz - peak velocity < 2.7mm/s (0.105 in./s)

It should be noted that this criterion is based on vertical sinusoidal vibration of a single frequency data. There is no established basis to evaluate the effect when two or more components of different frequencies are present. All data that were used to establish the boundaries were obtained with test subjects standing or seating on a hard seat (Wong, 2003).

ISO has developed and adopted a general guide for defining human tolerance to whole-body vibration, ISO 2631 (1997). This guide defines three distinct limits for whole-body vibration in the frequency range of 1-80 Hz, such as:

1. Exposure limits, which are related to the preservation of safety and should not be exceeded without special justification.

2. Fatigue or decreased proficiency boundaries, which are related to the preservation of working efficiency and are applied to such tasks as driving a road vehicle of a tractor.
3. Reduced comfort boundary, which are concerned with the preservation of comfort and are related to such functions as reading, writing and eating in a vehicle.

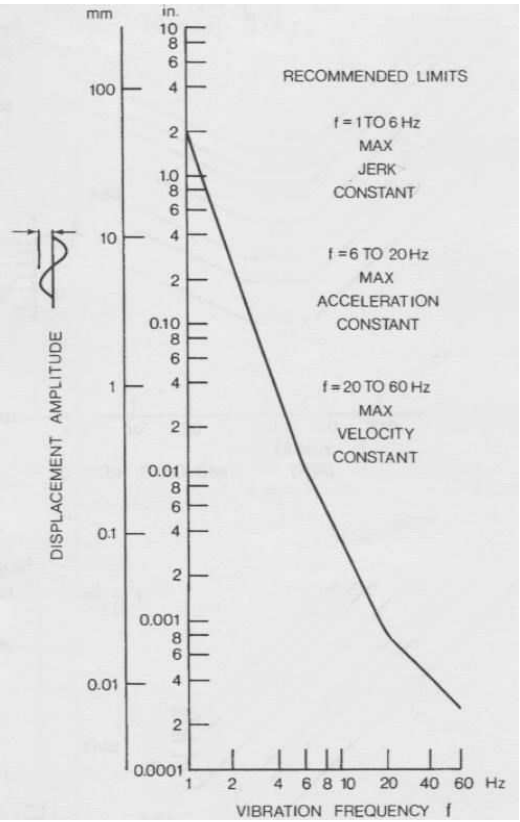
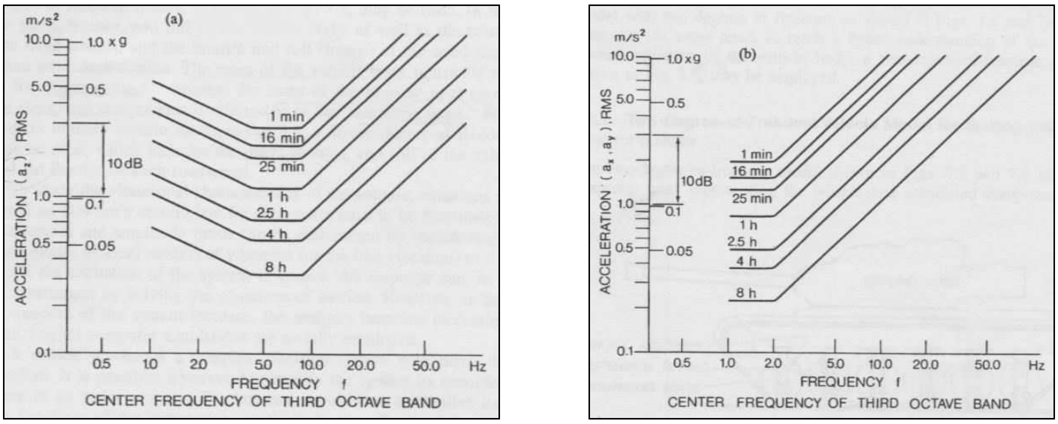


Fig. 1.1: Vertical vibration limits for passenger comfort proposed by Janeway (Wong, 2003).

Figure 1.2 shows the fatigue or decreased proficiency boundaries: (a) vertical vibration direction and (b) transverse or lateral direction which is defined in terms of root-mean-square values (RMS) of acceleration versus frequency for various exposure times. It can be observed that as exposure times increases, the boundary lowers.

Generally, the exposure limits for safety (or health) can be obtained by raising the boundaries by a factor of 2 and for the reduced comfort boundaries by a factor of 3.15.



a) vertical direction b) transverse direction

Fig. 1.2: Limits of whole-body vibration for fatigue or decreased proficiency for various exposure times, as recommended by ISO (Wong, 2003).

As for motion sickness, ISO 2631 (1997) suggest that the percentage of people who may vomit is proportional to the Motion Sickness Dosage Value (MSDV). This value is calculated by the square root of the integral of the square of the frequency weighted z-axis acceleration. A severe discomfort boundary and a reduced comfort boundary for various exposure times in the frequency range of 0.1-1 Hz has been recommended by ISO.

Another proposed parameter in evaluating human response to vibration is the absorbed power, which is the product of vibration force and velocity transmitted to the whole body. It is basically a measure of the rate at which vibration energy is absorbed by human. This parameter has been used mainly in military vehicle research and it has been reported that the tolerance limit is defined as at 6 W absorbed power at the driver’s position (Wong, 2003).

In short, extensive researches have been conducted to better understand on how to measure ride quality. However, they is no single, generally accepted approach. Several ride comfort criteria have been suggested but all are derived from various limitations in data and assumptions and far from the actual situation in vehicle vibration and motion.

1.3 VEHICLE SUSPENSION SYSTEM

Suspension system separates the axles from vehicle chassis, so that any road irregularities are not transmitted directly to the driver and the load on the vehicle. Suspension system affects both ride quality and handling performance of vehicle. As a matter of fact, ideal ride quality and handling performance pose a conflicting design requirement of vehicle suspension. While a lightly damped soft suspension yields good shock performance, hard suspension with high damping is desirable to achieved good handling. Active suspension system has been introduced as a promising alternative to overcome this traditional design limitation.

Suspension systems can be classified into passive system and active system, according to the existence of control input. The conventional passive suspension system consists of a typical spring and damper. It is the oldest system built by the principles outlined by Olley (1934) and gradually improved. Most vehicles used nowadays are using this system. Active suspension system can be further classified into two types – a semiactive system and a fully active system, according to the control input mechanism. While the fully active suspension system produces the control force through a separate hydraulic/pneumatic unit, the semiactive suspension system uses a varying damping force as control force (Hong *et al.*, 2002).

Semi-active and fully active systems are relatively new systems introduced as an attempt to overcome the shortcomings existed in the passive system. An optimal fully active suspension system is expected to be able to (Barak, 1992):

1. Optimize between ride comfort and road handling.
2. Control car attitude changes due to braking (dive), accelerating (lift) and cornering.
3. Maintain optimal system response independent of vehicle loads.
4. Faster system response time.

However, the improved performance is directly related with increased in hardware complexity, higher costs and diminished reliability. Semiactive suspension system was therefore introduced as a compromise between passive system and fully active system. In general, it improves ride without compromising the handling of vehicle as compared to passive system and at the same time less complexity and less costly than active system. Semiactive suspension system is the main focus in this work and the result is compared to the conventional passive system.

There are generally two types of semiactive damping system, namely electro-rheological (ER) damper or magneto-rheological (MR) damper. Magneto-rheological fluid (MRF) is used in MR damper. This MRF usually is a fluid such as hydrocarbon oil filled with randomly dispersed micron-sized magnetically polarizable iron. Additives usually are added to promote homogeneity and to prevent gravitational settling of the irons. This MRF exhibit a change in rheological properties from a free-flowing fluid state to a semi-solid state upon application of an external magnetic field. This change can be varied according to the strength of the applied magnetic field. The process is also reversible that upon removal of the magnetic field, the fluid will revert back to its original free-flowing state.