



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**VALIDATION AND IMPROVEMENT OF 14-DOF RIDE AND
HANDLING MODEL FOR PASSENGER VEHICLE**

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor's Degree in Mechanical Engineering Technology (Automotive Technology) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Automotive Technology) (Hons.). The member of the supervisory is as follow:

.....

(Project Supervisor)

ABSTRAK

Terdapat banyak model kenderaan yang telah dibina untuk kajian dinamik khususnya tingkah laku perjalanan dan pengendalian. Tesis ini menerangkan pembangunan model kenderaan untuk mengkaji tingkah laku kenderaan selepas peningkatan dengan sistem suspensi semi-aktif. Model kenderaan 14-DOF Terdiri daripada perjalanan, pengendalian dan model tayar telah dibina berdasarkan model terbitan. Pemilihan kombinasi yang tepat diantara pengawal dan penggerak akan dibuat berdasarkan keputusan perbandingan diantara MATLAB dan CARSIM untuk dipadankan dengan model 14-DOF. Semua andaian yang dibuat untuk 14-DOF dengan kenderaan semi-aktif sistem model dinyatakan. 14-DOF model kenderaan akan disahkan menggunakan perisian CARSIM. Keputusan yang dibincangkan adalah kadar rewang, pecutan sisi, sudut gulungan badan kenderaan dan Juga sudut gelincir pada setiap tayar.

ABSTRACT

There are many vehicle models that have been developed for the study of the vehicle dynamics specifically for the ride and handling behavior. This thesis describes the development of vehicle model to study the behavior of the vehicle after improvement with semi-active suspension system. The derivation of a 14 DOF vehicle model consists of ride, handling and tire model are presented. The most accurate combination of controller and actuator which follows the comparing result of the MATLAB with CARSIM software was chosen to be coupled with the 14 DOF model. All the assumptions made for the 14 DOF with semi-active system vehicle model is stated. The 14 DOF vehicle model will then be validate using CARSIM software. The results discuss suc as yaw rate, lateral acceleration and roll angle of the vehicle body and also the slip angle at each tire.

DEDICATION

Dedicated to my supportive mother, Mrs. Rubiah binti Ab. Rashid. To my supervisor, Engr. Nur Rashid bin Mat Nuri@Md Din, co-supervisor, Engr. Mohamad Hafiz bin Harun, lecturers and friends for all of their helps and friendship.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

DOF	-	Degree of Freedom
RLF	-	Radlastfactor
MR	-	Magneto-rheological
ER	-	Electro-rheological
RMS	-	Root Mean Square
DLC	-	Double Lane Change
m_s	-	Sprung mass
m_u	-	Unsprung mass
K	-	Stiffness
$\dot{\gamma}$	-	Yaw Angular Acceleration
\ddot{x}	-	Longitudinal axis acceleration
\ddot{y}	-	Lateral axis acceleration
L	-	Wheelbase
I_{zz}	-	Vertical axis moment of inertia
$\ddot{\theta}$	-	Pitch angular acceleration
$\ddot{\phi}$	-	Roll axis angular acceleration
I_{xx}	-	Longitudinal axis moment inertia
I_{yy}	-	Lateral axis moment inertia
φ	-	Viscosity
F_d	-	Force Damper
>	-	More than
\geq	-	More than or equal
<	-	Less than
\leq	-	Less than or equal
C_2	-	coefficient damper
Z	-	Displacement of suspension

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

This paper studies technology for a thesis of vehicle dynamics model based on selected parameter model to simulate driving characteristics vehicle control precisely. The purpose for road vehicle suspension design is to find a satisfying tolerance solution that can provide enough control of ride vibration, roll and pitch motions due to different motion and external excitations. Besides, the rotational motions together with the road roughness induced translational motions extremely influence the ride comfort, the load transfer affect tire force, cornering and braking forces. These changes directly influence the direction, braking dynamic responses and stability limits of road vehicles in a dynamic condition. Under various road surface and steering or braking movement, a full vehicle dynamic model is developed with semi-active system and validates to improve vehicle ride and handling dynamic response, suspension anti-roll and anti-pitch characteristics. MATLAB (Simulink) based on 14 DOF full vehicle model consists of ride vehicle model, handling vehicle model and tire model were constructed. 14 DOF result will compare with CARSIM to verify the best model at the end of this research.

1.2 Problem Statement

The problem statement is much suspension system that used linear model with decrease the number of degree of freedom (DOF). A quarter car models are very commonly used. Although this is basic model, it is important in vehicle dynamic for equilibrium analysis. These simple models do not give accurate result in suspension geometry calculation, except for the motion ratio. This leads to model inaccuracies when models are used to simulate vehicle behavior with extreme wheel travel typical off-road driving. Simplified models are also considered inaccurate when to study about transient's behavior. So the reason to use high number of DOF with the lumped mass model is that it is linear and the physical significance of variables is easy to study. With more complex models, the connection between real physical quantities and variables disappear easily. A quarter car models cannot demands with high multi objectives. Besides, the wide use of vehicles as an example for the theories of modern control technology, there are many different solutions for the vehicle suspension problem. The solutions obtained with this type of models can be adjustable with correct controller and actuator. Most of these solutions are virtually impossible to apply on real world vehicle but it is still keep going to find the possible solution for the improvement of car suspension.

1.3 Objective

- (i) To validate the MATLAB Simulink results with CARSIM software
- (ii) To improve the 14-DOF ride and handling model for passenger car by analyzing, selecting, the best parameter and choosing the best type of spring stiffness and suspension damping for suspension systems.

1.4 Scope

There are three parts for this study. First part is about 14-DOF model. It is represented by:

- (i) Handling vehicle model (3-DOF). It is consist of longitudinal translation, lateral translation, and rotation of vehicle mass center.
- (ii) Ride vehicle model (7-DOF). This model has 3-DOF of mass center (Vertical, roll, pitch dynamic) and 4-DOF of each wheel (wheel vertical dynamic).
- (iii) Tire model (4-DOF). It is consist of longitudinal 1-DOF of each tire.

For the second part, suspension system with variable parameter value of spring stiffness and damping suspension were chosen as a method to improve the suspension model. This method should control damper and suspension spring by using controller damper that can decrease the resonant peak of the body mass and give a good quality handling.

The last part, 14DOF car model together with passive suspension system have to be analyzed to get best result using MATLAB (Simulink) software. By comparing MATLAB result with CARSIM software, so the validation of fully dynamic vehicle model can be made.

CHAPTER 2

LITERATURE REVIEW

In this chapter the literature review is presented. It will discuss about general definition about vehicle suspension, different types of suspension model and control strategies for semi-active suspension.

2.1 Vehicle Suspension

Ride comfort is an important factor of the suspension system of vehicles. It is represented how much the vehicle give comfortable to the passenger. Ride comfort is very important for agricultural tractors, because the acceleration transmitting to the driver compared with other vehicles is very high (Horton&Crolla, 1984). Agricultural tractors same like passenger vehicle driver, the driver needs comfortable especially when travelling on the long distance. These conditions can affect the comfort, efficiency, alertness, and health of the driver.

Vibration sources that affect ride comfort are categorized generally into two classes, namely on-board sources and road sources (Jamei, 2002). The components have the wheels, the driveline, and the engine arise on-board sources from the rotating. These sources caused aural vibrations in the frequency region of 25 - 20,000 Hz, which are called "noise" (Gillespie, 1992). These two frequencies are the lower and higher frequency thresholds of human hearing. The road sources are the second category of the vibration sources of the vehicles, referring to the road roughness and maneuver excitations. Normally frequency range of these excitations is 0-25 Hz. This range frequency is natural frequency that most sensitive to human body area. So, the

most important factor in affecting ride comfort of a vehicle is road excitation sources.

Stable and safe driving car can be created with considered handling characteristics to make sure the contact between the tires and road surface. (Mitschke, 1984) defined a factor called RLF “Radlastfaktor” in order to quantify vehicle handling. For calculation, addition the vertical dynamic tire force with considering vertical static tire forces. RLF factor is equal to the value of the dynamic tire force over the value of the static tire force. The higher of this factor the higher instability in the tire contact. With RLF factor, handling of vehicles can be examines. This factor was also used by (Hoppe, 2006) in order to evaluate the handling capability of a full suspension tractor

2.2 Types of Suspension

There are two types of suspension will be discussed on this section. There are many types of suspension have been created in order to study about vehicle behavior. But these two suspensions are commonly used. So, the comparisons between them were made to choose the best one.

2.2.1 Fully active suspension system

Passive suspension use principle by storing vibration from vehicle and dissipates the energy with spring and a damper. It is different with fully active suspension that injects energy into the system by using a forces actuator which is placed between the sprung mass and unsprung mass. Figure 2.1 shows the fully active suspension.

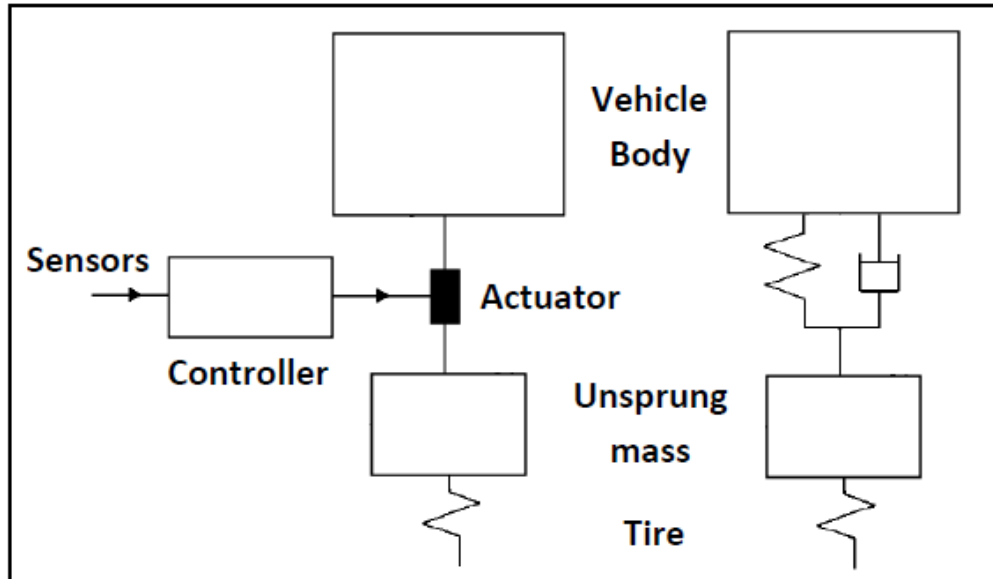


Figure 2.1: Fully active suspension model

This suspension model created to control over the full bandwidth of suspension system. The suspension response the natural frequencies of the vehicle body and wheels. These natural frequencies of typical vehicles are 1-3 Hz of the vehicle body and 5-15 Hz of the wheels (Williams, 1994). These systems cover the full bandwidth of the suspension system and are able to perform a complete control on the vibrations. This provides good ride comfort and road stability for vehicle. However, the high bandwidth control leads to a significant quantity of power consumption, which is approximately until 10 kW for the normal automobiles. This high power consumption can affect negatively the overall performance of the vehicle and increases the fuel consumption in the range of 10 – 15 % (Williams, 1994).

Besides, in a fully active system actuator are placed between passive suspension elements. That means, the malfunction of actuator can give big effect to the suspension. The stiffness of the damper cannot function well when error in actuator. This problem caused the performance of ride quality and road handling drop. In addition, stability and controllability of the vehicle critically reduce when strong wrong force by an actuator may cut the tire contact from the road surface. Then, vehicle and passenger exposed to the danger. Such situation may lead to create dangerous modes for vehicle and passenger (ShahriarSarami, 2009).

Although fully active system has many advantages but it also has their weakness. Normally, this system just used for luxury or special vehicles. So, in order to increase performance of this system, low-bandwidth type of these systems is created. In this new system, the actuator is arranged in series with a passive spring and passive damper. The more detailed about the low band-width fully active suspension model is represented on the Figure 2.2. On the contrary, the goals to improve the suspension response just around the natural frequencies of the body vehicle, with the typical range of 1-3 Hz, because these frequencies area has the main role in both ride comfort and handling of vehicles (ShahriarSarami, 2009).

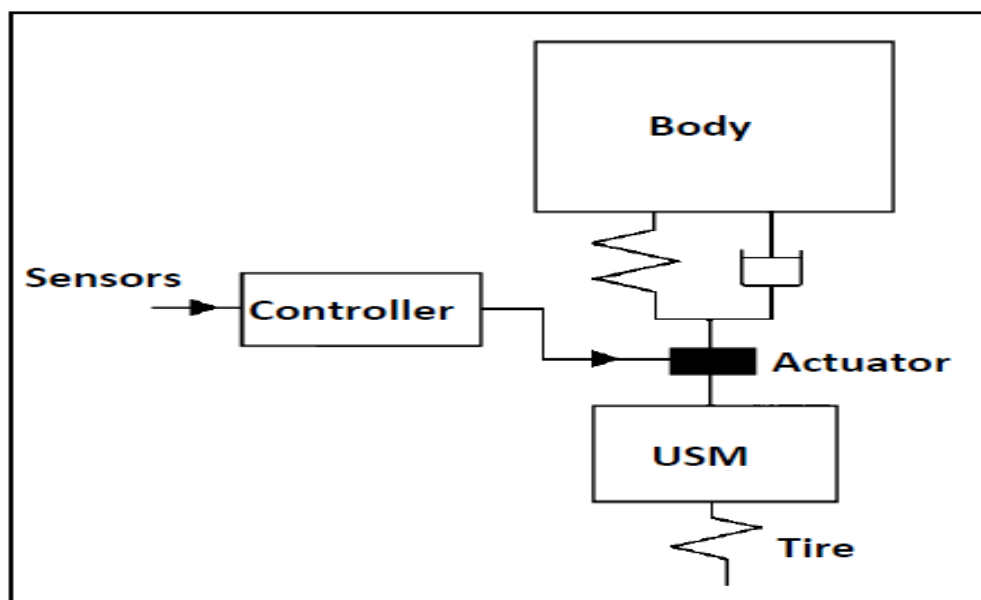


Figure 2.2: Configuration of a low-bandwidth active suspension (Williams, 1994)

2.2.2 Semi-active suspension system

The difference semi-active with fully active is active force generator is replaced with an adjustable damper. Semi-active system was illustrated on the figure 2-3 as comparison with fully active system. Using the controller damper, fast situation of the suspension motion can changes energy dissipation of the suspension system.

Another method to compare the difference between semi-active and fully active is about the working area. Based on the Figure 2.3 state by (ShahriarSarami, 2009), in a fully active system, the four operation areas are covered, because the force of the actuator can be applied to the system in direction or against the direction of the suspension movement. In spite of this, in a semi-active system, the force of the adjustable damper can be applied to the system only against the direction of the suspension movement. Thus, just two areas of the four operating areas are covered by this system.

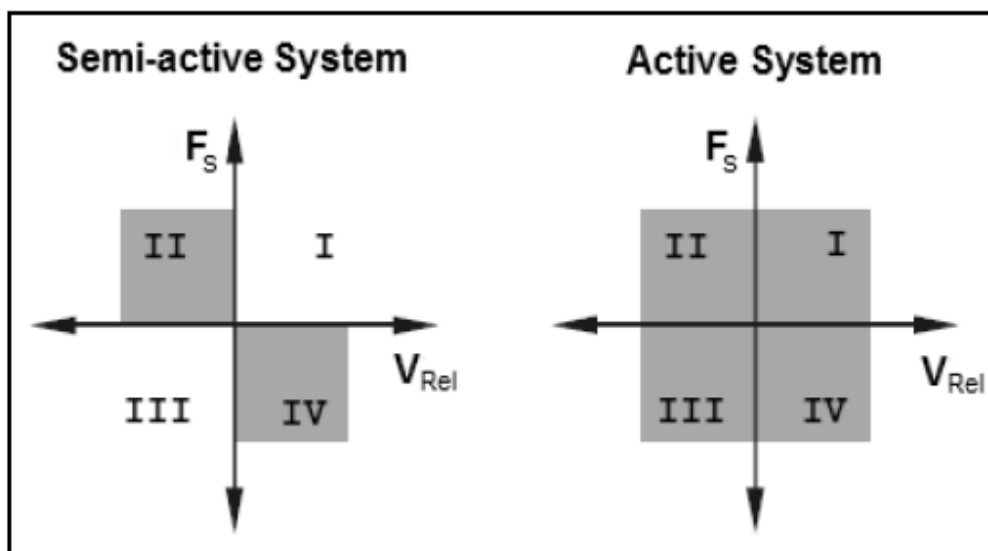


Figure 2.3: Working area of the semi-active and fully active suspension
(ShahriarSarami, 2009)

Basically the stiffness of the damper changes due to the viscosity hydraulic fluid in the damper. In this part, hydro-pneumatic and MR damper selected as literature review for actuator components. The first damper is hydro-pneumatic suspension. It has a controllable throttle-valve between the cylinder and accumulator. For the configuration of this damper it is shown on the Figure 2.4 below:

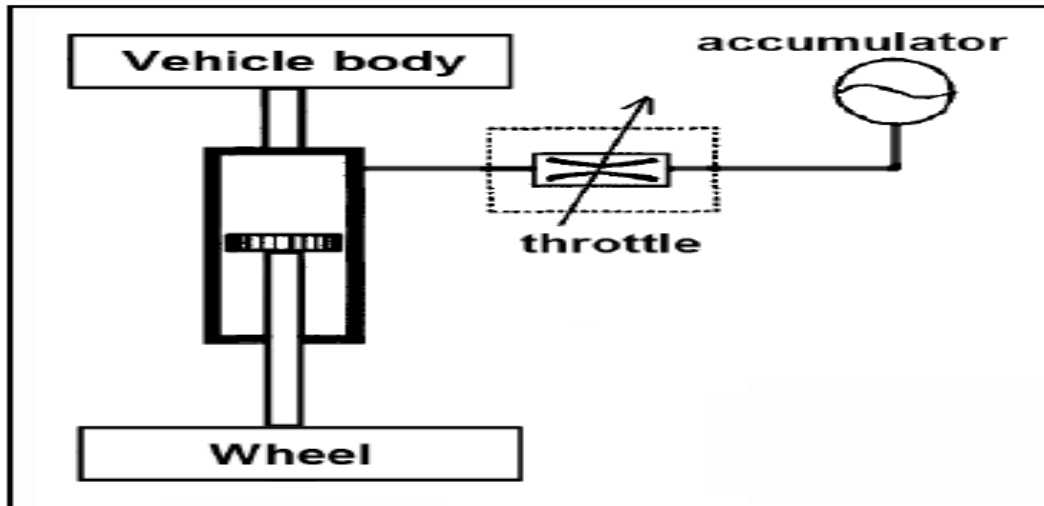


Figure 2.4: Hydro-pneumatic suspension with controllable throttle
(ShariarSarami, 2009)

Next, about MR damper suspension that uses viscosity principle hydraulic fluid instead of cross-area of the throttle of a damper. This damper has two types. The types determined by the types of fluid used that is electro-rheological (ER) fluid or magneto-rheological (MR) fluid. Magnetic field is a controller to control the viscosity of the fluid. Each of the fluid has their own specialty. Figure 2.5 is shown about the model of MR damper in schematic illustration.

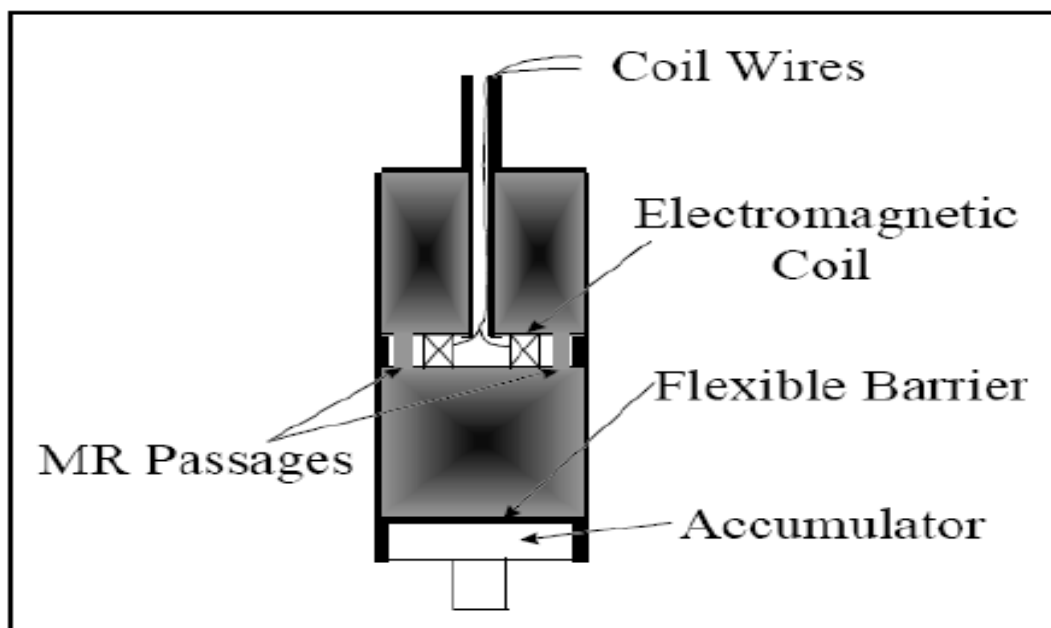


Figure 2.5: Schematic illustration of a MR damper (Pare', 1998)

MR damper can response in the short time, it about of millisecond. This is important in a semi-active control system, because among all components of this control system, the time response of the actuator is the most limiting factors in order to create the proper control bandwidth (Mäkelä, 1999).MR dampers has priority to the ER dampers inpracticable application (Goncalves, 2001), because they can be directly operated by the electricity source of a vehicle.

Considered about the failure, semi-active system is less than fully active system in the aspect of operation. Passive damping is created by control damping force. Without building a critical situation in the vehicle, the efficiency will be decreased. The advantages of semi active system are the construction is not complicated, cheaper, and have low energy consumption. Based on these performances, semi-active system are usually preferred over fully active suspension. Besides, many car companies considered with semi-active in order to save their cost. For the heavy vehicles, semi-active suspensions are preferred particularly as a practicable way in order to improve their suspension performance (Efatpenah, Beno, & Nichols, 2000).

2.2.3 Conclusion for suspension

In the discussion above, for the vehicle performance chassis suspension intended to improve by using active suspensions. It is started with identified the component that involved in the active suspension. After that, types of suspension were described and do comparison with semi-active system and fully active system in order to choose the best suspension. Based on the (ShahriarSarami, 2009), Table 2.1 was created.

On the table considered with the factor efficiency, energy consumption complexity and cost, control bandwidth, operation condition consideration and failure mode problem. Every types of suspension were gives their score based on the factor listed before. After that, the result of sum point can be as reference to identify which one the best types of suspension. About on the table, it was discussed about