" I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of degree of Bachelor Mechanical Engineering(Automotive)"

Signature :..

Supervisor : MOHD SAFARUDIN

Date : 4 MAY 2007

IMPROVEMENT OF RIDE QUALITY OF PASSENGER VEHICLE USING THE SEMI-ACTIVE SUSPENSION SYSTEM

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This report is hand over to the Faculty of Mechanical Engineering to fulfill the stipulation of Bachelor of Mechanical Engineering graduation.

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

May 2007

" I declare that this thesis is the results of my own research except as in cited references"

Signature : ....

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Date : 9 MAY 2007

ABSTRAK

Kualiti pemanduan adalah suatu pengukuran keselesaan untuk sesebuah kenderaan lebih-lebih lagi kenderaan penumpang. Ianya diukur berdasarkan berapa banyak getaran yang diterima oleh badan kenderaan apabila sesebuah kenderaan itu melalui sesuatu permukaan jalan. Banyak kajian yang telah dijalankan untuk menjadikan kualit pemanduan ini lebih berkualiti. Kajian yang paling mendapat perhatian pengkaji-pengkaji adalah kajian terhadap sistem suspensi. Tesis ini mengkaji tentang sistem suspensi semi-aktif, salah satu daripada sistem suspensi kenderaan, dan kebaikanya terhadap kuliti pemanduan. Kaedah kawalan yang dikaji adalah kaedah kawalan "hybrid" iaitu gabungan daripada kaedah *Skyhook* dan kaedah *Groundhook*. Berdasarkan kajian, terdapat perubahan yang lebih baik apabila sistem suspensi sesebuah kenderaan mengggunakan sistem semi-aktif. Kajian ini merangkumi perihal kenderaan pada *pitch* dan *bounce*. Kajian ini telah menggunakan perisian Matlab degan menggunakan simulink.

ABSTRACT

Ride is the major component of a vehicle's comfort. Ride problems occur when the vehicle's suspension failed to absorb force from the tire on different type of road surfaces. This failure makes the unwanted vibrations. This is the main problem for every cars and vehicles. It can cause many type of problem due to passenger comfort and vehicle stability. There are many researches that have been proposed to make the ride quality better. One of it is research on suspension system. This thesis studied vehicle behaviors on pitch and bounce using the semi-active suspension system. The control strategies that have been studied is the hybrid control strategy, which is combination of Skyhook and Groundhook control strategies. There are improvements using the semi-active suspension system. This research used the Simulink program in Matlab software.

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LIST OF SYMBOLS

SYMBOLS	DEFINITION
Ms	Sprung mass
Mu	Unsprung mass
Fs	Forces by spring
Fd	Forces by damper
Ft	Forces by tire
Fw	Forces on wheel
fr	Front right
fl	Front left
fr	Rear right
fl	Rear left
Mr	Roll momen
Mp	Pitch momen
Ir	roll inertia
Ip	Pitch inertia
Zb	Body displacement

GREEK'S SYMBOLS	DEFINITION
β	Roll angle
θ	Pitch angle

CHAPTER 1

INTRODUCTION

This chapter consist the objective and the scope of the project. It also includes the introduction of vehicle dynamic and ride quality. Under the sub-title ride quality, there is also some discussion about the problems of ride quality that affected on vehicle and human.

1.1 Objective

The objective of this project is to design and study a control algorithm for semi-active suspension system that can improve the ride quality of a passenger vehicle.

1.2 Scope of project

The scope of this project is to develop a control algorithm of a semi-active suspension system. The scope is also covered the development of vehicle model in vertical dynamics. The controller design of the application of semi-active suspension system in the vehicle model also one of this study's scope. This project only covered simulation result for the body displacement and pitch of the vehicle.

1.3 Vehicle dynamic

Vehicle dynamic, as we use as the term, is the branch of engineering which relates tyre and aerodynamic forces to overall vehicle accelerations, velocities and motions, using Newton's Laws of Motion. It encompasses the behavior of the vehicle as affected by driveline, tyres, aerodynamics, and chassis characteristics. The subject is a complex one because of the large number of variable involved.

In general the characteristics of vehicle dynamics maybe described in terms of its performance, handling and simulations. A performance characteristic refers the ability of the vehicle to accelerates, to develop drawbar bull to overcome obstacle and decelerate. Handling qualities are concerned with the response of the vehicle commands and its ability to stabilize its motion against external disturbance. Ride characteristics are related to the vibration of the vehicle excited by the surface irregularities and it effect on passenger and goods. Therefore the theory of vehicle dynamics is concerned with the study of performance, handling and ride relationships with design of the vehicle under various operating conditions. In as much as the performance of the vehicle, the motion accomplished in accelerating, braking, cornering and ride is a response to force imposed, much as of the study of vehicle dynamics must involves the study of how and whythe forces are produced.

1.4 Ride quality.

Ride & handling have always been a compromise - technology has over time allowed automakers to combine more of both features in the same vehicle. High levels of comfort are difficult to reconcile with a low centre of gravity, body roll resistance, low angular inertia, support for the driver, steering feel and other characteristics that make a car handle well. Some of modern vehicle are now provide with many electronic system to improve its handling stability, provide comfortable driving, and increase passenger safety and health. We can see the features such as ABS, EBD, VSC (vehicle stability control) and many more.

Ride quality is measured in terms of the level of isolation from road inputs the suspension transfers to the vehicle without compromising vehicle control. Ride is the major component of a vehicle's comfort. Ride problems occur when the vehicle's suspension failed to absorb force from the tire on different type of road surfaces. This failure makes the unwanted vibrations. This is the main problem for every cars and vehicles. It can cause many type of problem due to passenger comfort and vehicle stability.

As we can see in automotive industry, ride comfort is also one of the criteria that must be considered. Good ride comfort in vehicle can attract people to experience the quality of good vehicle ride and controlling. The important of ride comfort is to improve vehicle stability and provide comfortable aspect to the drivers. Vehicle ride comfort is also related to vehicle and driver safety. And for the driver, in terms of healthy, it is also a good choice if they choose a vehicle with a very good ride quality.

According to research, a poor ride quality can cause bad injuries to the back bone. It can cause serious back pain. It also can make our bone joint feel uncomforted. So, with a better ride quality, this kind of pain can be avoided.

Vibration that cause by road excitation will make the part of the vehicle vibrate greater. This scenario will cause the joining part become easily worn out. With the semi-active system, it can reduce the vibration and the joining part in a vehicle has long life cycle.

CHAPTER 2

LITTERATURE REVIEW

This chapter is about some history of suspension. How the suspension is developed until it becomes the semi active system. There is some literature review about the semi-active system. In this chapter, there is also some history about the Magnetorheological Damper that use in the semi-active suspension system.

2.1 Magnetorheological fluid

In recent years, magnetorheological (MR) dampers have received much attention as semi-active system actuators for their rapid response to the applied magnetic field and their compact size. The MR effect was first observed by Jacob Rabinow in 1948. In the late 1980s and 1990s, researchers began to get serious about developing the commercial viability of MR fluids, especially when other technologies began to converge that made their use practical and a real possibility. Microprocessors, sensor technologies and increasing electronic content and processing speeds have created control possibilities that didn't exist in Rabinow's time.

The MR fluid was initially defined as the magnetically induced fibrillation of micrometer-sized magnetically particles suspended in low viscosity fluid. Without the magnetic field effect, the MR fluid has the properties of a Newtonian fluid; however, when the MR fluid is under the effect of magnetic field, the particles aligned themselves with respect the magnetic field and form into chains or columns, which make the viscosity of the MR fluid change

MR fluid is composed of oil and varying percentages of iron particles that have been coated with an anti-coagulant material. When inactive, MR fluid behaves as ordinary oil, but it exposed to a magnetic field, micron size iron particles that are dispersed throughout the fluid align themselves along magnetic flux line (James Poynor).

The iron particle can be described as large number of microscopic spherical beads and the flux line as very thin string. After the MR fluid magnetize, this microscopic spherical beads will be threaded onto the thin string. The thin string stretch from on magnetic pole to the other and perpendicular to each paramagnetic pole surface. These strings of beads placed closely together and can be pictured as the bristles of a toothbrush. Once aligned, the iron particles resist being moved out of their respective flux lines and act as barrier to fluid flow.

MR fluid have many attractive features, including high yield strength, low viscosity and stable hysteretic behavior over a broad temperature range(Carlson JD,1994). However, the principal handicap of fluids and the barrier of their widespread commercial acceptance in many areas is still their relative high cost.

Controllable fluid such as electrorheological (ER) and magnetorheological (MR) have recently attracted extensive interest because of their quick response, reversible behavior changes when subjected to electric or magnetic fields. In the past decades, diverse ER and MR damping devices have been developed for research and industrial applications (Stanway R.Sproston J L and El-Waheed A K, 1996). These devices usually work according to one or three flow modes or some combination of three. These mode operations are referred to as squeeze mode, valve mode and shear mode. A device that use the squeeze mode has a thin film (on order of 0.02 in.) of MP fluid that sandwich between paramagnetic pole surfaces as shown in figure 2.1. For devices that operate in shear mode has a thin layer (≈ 0.005 to 0.015 in.) of MR fluid sandwiched between two paramagnetic pole surfaces as shown in figure 2.2. Shear mod is useful primarily for dampers that are not required to produce large forces and for clutches and brakes. The valve mode is the most widely use among these three modes. A device operates in valve mode when the MR fluid is used to impede the flow of MR fluid from one reservoir to another.

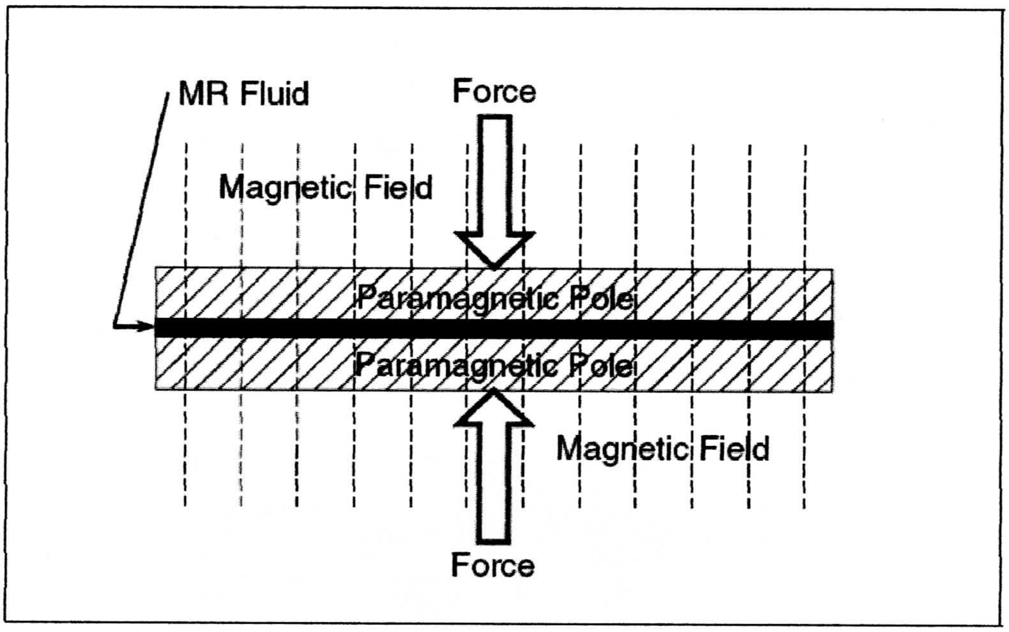

Figure 2.1 Squeeze mode

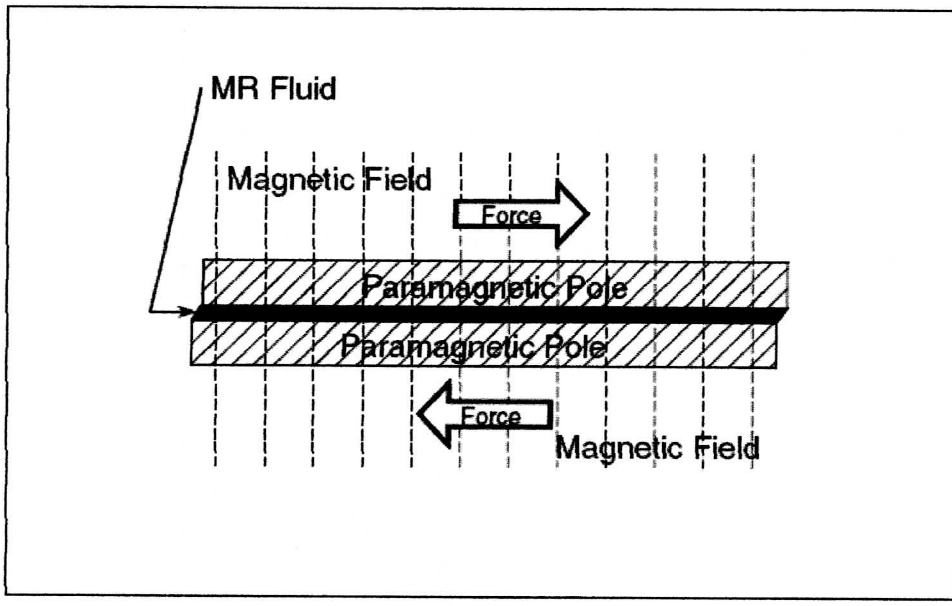

Figure 2.2 Shear mode

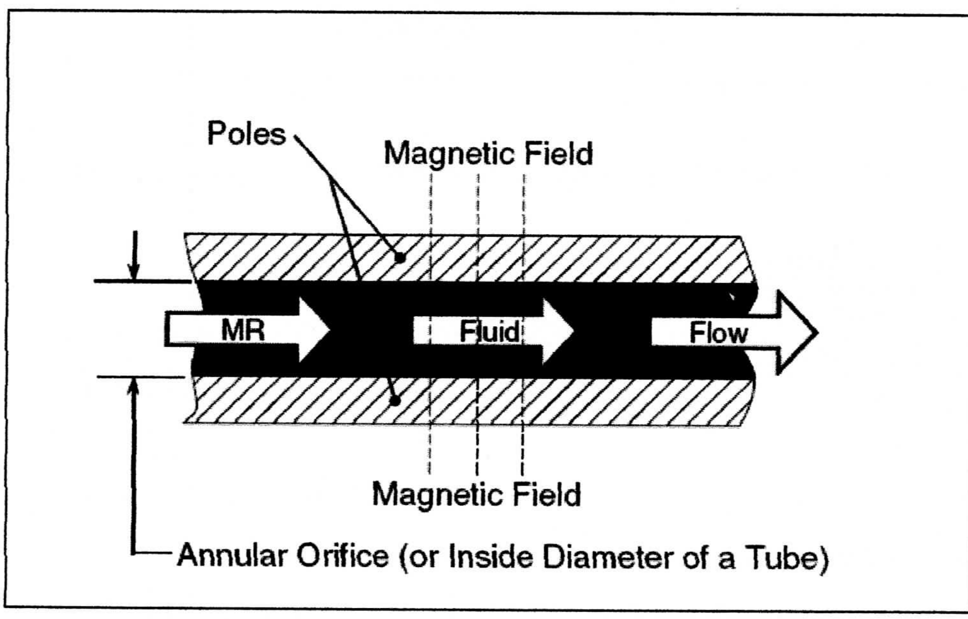

Figure 2.3 Valve mode

Controllable shock absorbers can potentially be used in a variety of other mechanical systems such as automotive engines and sports equipment. Most recently, even the military has shown interest in using MR dampers to control gun recoil on naval gun turrets and field artillery. Controllable MR fluid devices have equally been tested for braking wind turbines (Oualla J, Thomas M and Lafleur F,2003) and in domestic appliances such as washing machines (Chrzan M J and Carlson J D 2001) , joysticks, steering wheels and for furniture positioning, latching and locking elements as well as a host of automotive applications. Figure 2.4 shows the cross section of a magnetorheological devices such as the mgnetorheological dampers.

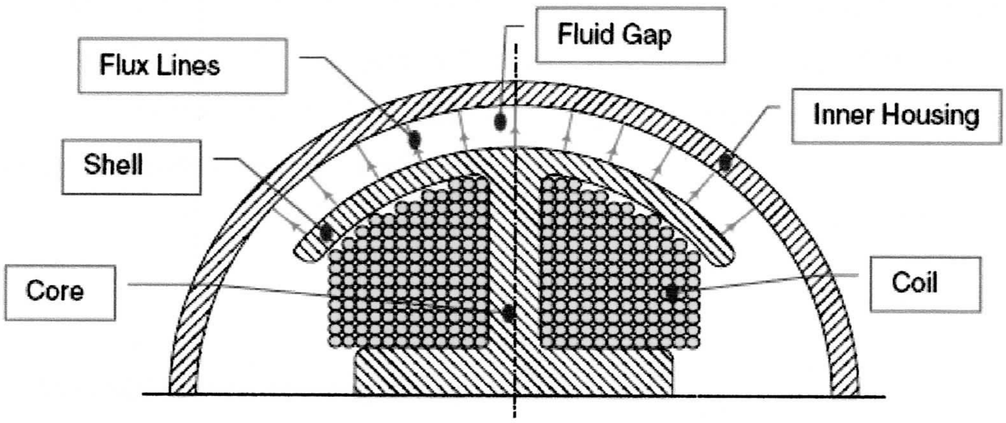

Figure 2.4 A model that shows how is inside the magnetorheological fluid devices

2.2 Magnetorheological dampers for automotive uses

Recently, many types of semi-active ER or MR dampers have been proposed for the vibration attenuation of various dynamic systems including vehicle suspensions. It starts commercialize in early 1998 as a vibration control system based on MR fluid shock absorbers for eighteen-wheel truck's seat. In 1999, MR fluid based adjustable shock absorbers for stock car and drag race vehicles were introduced.

The most interesting in the MR technology, a new way of using the MR fluids was developed (Carlson J D 1998). Such 'MR sponge' devices contain MR fluid that is constrained by capillary action in an absorbent matrix such as a sponge or open celled foam. The sponge is used to keep the MR fluid within the active area of the device where the magnetic field is applied. The sponge allows a minimum volume of MR fluid to be operated in a direct shear mode without seals, bearings or precision mechanical tolerances. Sponges are not susceptible to gravitational settling or sedimentation of the MR fluid suspension.

At University of Nevada, a new MR damper design for high mobility multi-purpose wheeled vehicles (HMMWV) was proposed (Dogruer U, Gordaninejad F and Evrensel C A 2004). The semi-active MR damper was designed to deal with rough road environment. This MR valve was designed to produce higher MR forces as compared to a channel cross-section MR valve.

2.3 Semi active suspension system

A semi active suspension system varies the damping forces in real time depending on the dynamics of the controlled masses. The semi active system utilizes a feedback loop to control the damping forces at any time. A processor can use the feedback data to calculate the desired damper control force, which must be converted to control signal before the damper can adjust by the system. The signals that is sent, changes the damper's resistance to velocity and therefore changes the damping force. Finally the feedback loop is completed. If the system works as desired, then the semi active system dynamics will be more favorable than the passive system dynamics.

Semi active dampers are an alternative to the active dampers. The design of the semi active control is just a little different from the passive control. The semi active dampers only dissipate energy in a controlled system. Imagine by holding a rod in hand, and let the rod slip. By tightening our grip the rod, we can control the dissipation of the potential energy stored in the rod as well as it slip. To represent semi active damper by the rod analogy, we can consider holding the rod firmly in one hand and loosely in the other. By pushing the rod up and down, we can represent the concept of active damper control. The active suspension dampers are capable of supplying energy to the system, such as hydraulic piston (John W. Masi, 2001)

There is two type of semi active damper, damper that use adjustable orifice and damper that use rheological fluid like magnetorheological fluid and electorheological fluid.

The advantage of semi active damper over active dampers is their low in complexity, cost, risk and weight. For semi active, it does away the use for the compressor, reservoir and valving(Crosby, M. J., Harwood, R. A., and Karnopp, D, 1973) So, the system is lighter than the active system. Although MR fluid is not inexpensive, but in term of safety and risk, a malfunction of an active damper is worst than semi actives. With all this advantages and factors suggest that the semi active is better than the active and the MR dampers favorable alternative to the active dampers.

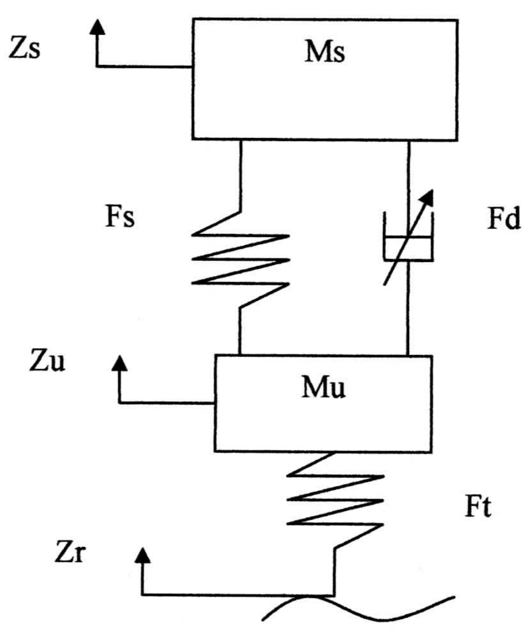

Figure 2.5 Two degree of freedom for the semi-active suspension system

Figure 2.6 show the passive suspension system. a semi active just the same as this but it use magnetorheological damper or elctorheological damper and this system has control loop.

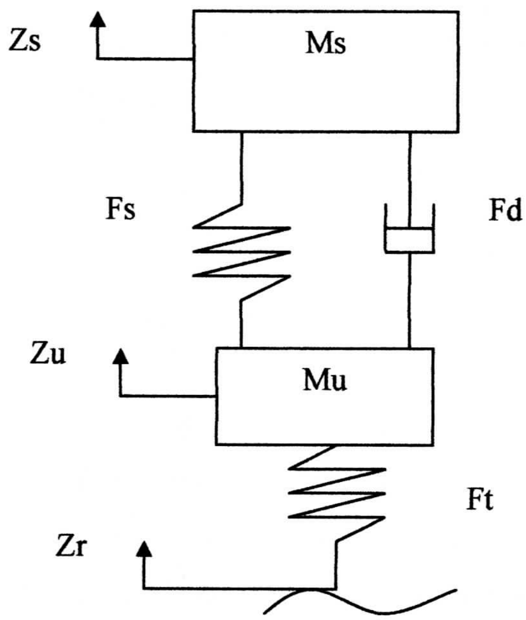

Figure 2.6 Two degree of freedom for the semi-active suspension system

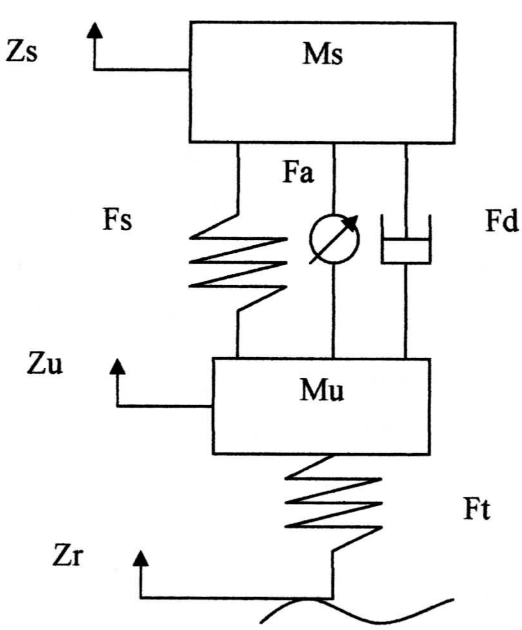

Figure 2.7 Two degree of freedom for the active suspension system

Now days, lot of car maker use the technology of semi active suspension system to aim the better ride, handling and comfort of their car. Huge car manufacturer like Ferrari will not give this chance up. One of their models, Ferrari 599 GTB Fiorano just been installed with semi active suspension system by their partnership, Delphi Corporation. Audi TT also equipped with this system by the same company, Delphi Corporation.

2.4 Control systems for the semi-active system

Active and semi-active suspensions have been used as a practical application for modern control theory for a long time. There are plenty of reasons for this. The ground vehicle represents a true MIMO-system with interdependencies that can be calculated if certain simplifications and linearization are made. The interdependencies are also relatively easy to perceive compared to matching properties of chemical reactions for example. Ground vehicles also represent a highly universal example, because practically everybody has driven a passenger car, at least in industrialized countries.

In most of the research done in this area of study, a linearized quarter car model is used. A simple reason for this is that different widely known optimal or robust control schemes (LQR, H∞ etc.) can be derived relatively easily for this model and it is considered that it manages to capture the basic features of a real vehicle problem (e.g.ElMadany & Abduljabbar 1999). A quarter car models are also easy to perceive as a system with multiple objectives, which are partly opposite.

Most of the studies are concentrating on controlling the forces created by the suspension damper and springs. There are a few studies that have concentrated on altering the kinematic properties of a suspension system (e.g. Lee et al. 2001, Watanabe & Sharp 1999, Sharp 1998). At the moment, these systems have more academic interest than practical applications; however, a few prototypes have been built.

In the literature many optimal and robust control approaches and algorithms can be found for automotive suspension systems. In this chapter, a few of these will be reviewed. They are chosen in a manner that they represent an example of the particular control approach. Two widely known control approaches, namely the sky-hook and ground-hook approaches are reviewed more deeply.

2.5 Sky-hook control

A widely known and widely used control scheme for controlling the vibration of the vehicle body is sky-hook damping presented by D. C. Karnopp (Karnopp et al. 1974). There is a wide range of different optimal suspension control approaches, but the skyhook approach is generally used for two purposes: as the ideal concept for comparison of the other control approaches and as the basis of practical implementation of semi active or active vehicle suspensions (Valášek et al. 1997).

Sky-hook damping represents an optimal control strategy in the sense that it minimizes the mean square velocity of the vehicle body if excitation is considered as white Gaussian noise. The basis of the skyhook damping theory lies in the LQR approach (Fuller et al. 1996). The theory of skyhook damping is derived with a simple mass-spring-damper system. The state equation then becomes so simple that the Riccati equation can be solved analytically. It has been used in damping of systems with multiple degrees of freedom by assuming that the different vibration modes appear independently. In this case, the vibration problem can be divided into many single degrees of a freedom problem (Karnopp et al. 1974, Nagai & Hasegawa 1997). An automotive suspension application of the sky-hook theory is found on the VW Phaeton. With skyhook damping, vehicle body Eigen frequencies of below 1Hz have been achieved (Eichler et al. 2002). The idea of skyhook-suspension can be