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Supervisor 2	: ..……………………..
Date	: ………………………

THE DEVELOPMENT OF AN ACTIVE ROLL CONTROL FOR HEAVY VEHICLE

MOHD FIRDAUS BIN MOHD HUSSAIN

This thesis is submitted to the Faculty of Mechanical Engineering, in partial fulfillment of the partial requirement for the Bachelor of Mechanical Engineering (Automotive)

FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

May, 2008

"I declare that this report is my own work accept any summary or quotation that every single sources are explained"

Signature : ……………...………………………

Author : MOHD FIRDAUS BIN MOHD HUSSAIN

Date : 27 MARCH 2008

To my beloved mother, father, brothers and sisters,

All my sweet friends

All members of Bachelor of Mechanical Automotive (BMCA)

My PSM supervisor, Mr. Mochamad Safarudin

All lecturers from BMCA Department

Staff of Faculty Mechanical Engineering

Staff of Universiti Teknikal Malaysia Melaka (UTEM)

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ABSTRACT

Active roll control system consist actuators to improve the roll stability for the heavy vehicle. This project will be designed controller to prevent roll over. This project review a heavy vehicle dynamic model for simulating the roll and handling performance using the software provided. From the full-car model, the mechanism of the roll over process for controlling load transfer to stability will be analyzed. The best achievable control objective for maximizing roll stability is shown to be balancing the normalized load transfers at all critical axles while taking the largest inward suspension roll angle to the maximum allowable angle. The procedure to analyze the roll over is using full car model. From the full car model, the equation will be derived and then use MATLAB Simulink to find the result. A more practical controller, using measurements of suspension roll angles, body roll rate and steering input, is also described.

ABSTRAK

Sistem aktif kawalan balikan menggunakan alat yang menukarkan tenaga hidraulik kepada tenaga mekanikal untuk penambahbaikkan keseimbangan kenderaan berat. Projek ini akan merekabentuk system kawalan untuk mengelak kenderaan terbalik. Projek ini akan menjalankan ujikaji keseimbangan dan pemanduan terhadap dinamik kenderaan berat menggunakan program yang telah disediakan. Daripada model penuh kenderaan, satu mekanisme untuk menganalisis beban berat terhadap kesimbangan dijalankan.Objektif terbaik yang hendak di capai adalah memaksimumkan kesimbangan kenderaan terhadap bebanan dengan mengambil kira sudut keterbalikan system ampungan dan sudut-sudut yang berkaitan. Persamaan- persamaan akan diungkai melalui model penuh kenderaan dan dijalankan analisa menggunakkan program MATLAB Simulink. Pengiraan dan sistem kawalan yang lebih lagi seperti sudut balikkan, kadar terbalikkan kenderaan juga di terangkan.

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NOMENCLATURE

Ks	suspension stiffness
Cd	suspension damper
Fa	an active force actuator
Mb	body mass
Fb	body force
Ms	sprung mass
Kt	tire stiffness
I_{yy}	inertia of pitching
I_{xx}	inertia of rolling
a	distance of centre of gravity from front axle (m)
b	distance of centre of gravity from rear axle (m)
c/t	track width (m)
h c.g.	height (m)
*h*rcf	front roll center distance below sprung mass centre of gravity (m)
*h*rcr	rear roll center distance below sprung mass centre of gravity (m)
Jx	roll inertia (kg m2)
Jy	pitch inertia (kg m2)
Jz	yaw inertia (kg m2)
M	vehicle sprung mass (kg)
u/v/w	longitudinal/lateral/vertical velocities of centre of gravity in body-fixed coordinate (m/s)
θ	pitch angle (rad)
φ	roll angle (rad)
ψ	yaw angle (rad)
$\omega x/\omega y/\omega z$	roll rate/pitch rate/yaw rate of c.g. in body-fixed coordinate (rad/s)
*b*s	suspension damping coefficient (Ns/m)

$F_{xt}/F_{yt}/F_{zt}$	tire longitudinal/lateral/vertical forces (N)
$F_{xg}/F_{yg}/F_{zg}$	longitudinal/lateral/vertical forces at tire contact patch in coordinate frame (N)
$F_{xgs}/F_{ygs}/F_{zgs}$	longitudinal/lateral/vertical forces at tire contact patch (N)
$F_{xs}/F_{ys}/F_{zs}$	longitudinal/lateral/vertical forces transferred to body (N)
J_w	rotational inertia of each wheel (kg m2)
m_u	unsprung mass (kg)
r	tire radius (m)
s	tire longitudinal slip
α	tire lateral slip (rad)
ω	angular velocity of wheel rotation (rad/s)
δ	road wheel steer angle (rad)

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CHAPTER 1

INTRODUCTION

This chapter will provide the information about overview of the research conducted for this thesis. First, the overviews about active roll control system for heavy vehicle, then the equations and methods for active roll system will be presented.

Rollover for heavy vehicle

Heavy vehicles are commercially used to transport goods and are due to strong competition operated by very cost sensitive owners. Small medium heavy trucks are bought by customers with the purpose of being as profitable as possible, in other words to transport as large amount of goods as fast and cheap as possible. New technology is therefore not easily introduced if it in the end doesn't bring a cost reduction to the customer. As a result small medium heavy trucks are designed such that chassis suspension components and anti roll bar are chosen for reliability and cost rather than technology.

Rollover may be defined as any maneuver in which the vehicle rotates 90 degrees or more about its longitudinal axis such that the body makes contact with the ground. Rollover may be precipitated from one or a combination of factors. It may occur on flat and level surfaces when the lateral accelerations on a vehicle reach a level beyond that which can be compensated by lateral weight shift on the tires. Cross-slope of the road (or off-road) surface may contribute along with disturbances to the lateral forces arising from curb impacts, soft ground, or other obstructions that may “trip” the vehicle.

The rollover of heavy vehicles is an important road safety problem in the worldwide. Several studies have been reported from US National Highway Traffic Safety Administration that the serious heavy vehicle accidents involve rollover. The review of heavy vehicle safety considers that while some rollover accidents to articulated vehicles were unnecessary given a complicated warning system and highly skilled driver, the majority could not only be avoided by the involvement of advanced active systems. It is very difficult for truck drivers to observe their proximity to rollover while driving.

The basic limitations in roll stability for vehicles with active roll control systems are not well understood. An understanding of these limitations is necessary to enable the formulation of achievable control system design objectives that maximize vehicle roll stability. It is clear that even increase in roll stability can lead to a significant reduction in the frequency of rollover accident. This provides a study to improve roll stability of heavy vehicle because of the serious safety; cost and environmental implications of rollover accidents.

1.2 Problem Statement

Three major causes of rollover have been identified. The first problem contributing factors of rollover is sudden course deviation which is combination between heavy braking and high initial speed. The other factors are excessive speed on speed and shifting load.

Therefore, this report will design and implement of an active roll control system for a heavy vehicle. A simple yaw roll model of small medium heavy vehicle is developed, validated and used for control design.

1.3 Objective

The objective of this project is design active roll control system to prevent roll over of heavy vehicle and also to provide the vehicle with an ability to resist overturning moments generated during cornering and speeding.

1.4 Scope

The scope of this project is to create the conceptual design of active roll control system for small medium heavy vehicle, actuator selection and basic controller design for further study.

CHAPTER 2

LITERATURE REVIEW

In the development of active roll control systems, a vehicle model that can represent realistic roll behavior is essential to predict impending rollover as well as accurately applying the actuation force to avoid vehicle rollover.

2.1 Roll stability

Roll stability refers to the ability of a vehicle to resist overturning moments generated during cornering and speeding, that is, to avoid rollover. Roll stability is determined by the height of the center of mass, the track width and the kinematic and properties of suspension.

The roll dynamics of heavy vehicles when cornering are much more relevant to vehicle safety than those of automobiles. Heavy vehicles feature relatively high centers of mass and narrow track widths and can lose roll stability at moderate levels of lateral acceleration. Whereas the performance limit of an automobile is characterized by a loss of yaw stability, the performance limit of a heavy vehicle is typically characterized by a loss of roll stability

The rollover threshold differs particularly among the various types of vehicles on the road. As examples, typical values fall in the following ranges

Table 1: Rollover Threshold for Road Vehicle
(Source: Thomas D. Gillespie, 1992)

Vehicle Type	CG Height	Tread	Rollover Threshold
Sports car	18-20 inches	50-60 inches	1.2-1.7 g
Compact car	20-23	50-60	1.1-1.5
Luxury car	20-24	60-65	1.2-1.6
Pickup truck	30-35	65-70	0.9-1.1
Passenger van	30-40	65-70	0.8-1.1
Medium truck	45-55	65-75	0.6-0.8
Heavy truck	60-85	70-72	0.4-0.6

The connection between lateral acceleration and roll angle can be derived by the overload lateral acceleration produces a roll acceleration that further increases the angle driving away from the equilibrium point. In order to be in equilibrium, the vehicle roll angle must be at the precise value on the above curve where the equilibrium lateral acceleration matches the actual as shown in chart below.

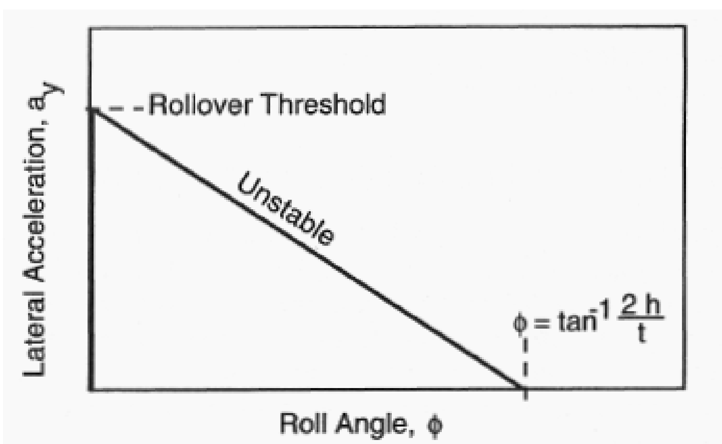

Figure 2.1: Equilibrium lateral acceleration in rollover of a rigid vehicle.
(Source: Thomas D. Gillespie, 1992)

The roll angle can overshoot means that wheel lift-off may occur at lower levels of lateral acceleration input in transient maneuvers. A step steer maneuver that produces a lateral acceleration level just below the static threshold can result in rollover in the transient case because of the overshoot. Thus the roll angle versus time results should be like the graph below.

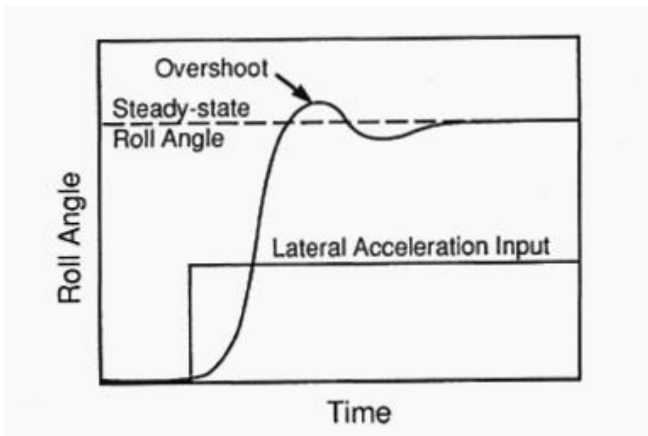

Figure 2.2: Roll response to a step input.
(Source: Thomas D. Gillespie, 1992)

The extent to which overshoot occurs is dependent on roll damping. The lowest rollover threshold occurs when there is no damping. Even so, the benefits of roll damping are evident. The rollover threshold for the vehicle increases by nearly one-third in going from zero to 50 percent of critical damping. For the heavy truck the reduction is nearly 50 percent.

2.2 Anti roll bar

The active roll control system consists of a stiff U-shaped anti-roll bar, connected at each end to the trailing arms, and two hydraulic actuators located between the chassis and anti-roll bar (Figure 2.3). The actuators apply equal and opposite vertical loads to the bar, thereby twisting it, and applying a roll moment to the vehicle body. The result is a floating anti-roll bar whose position is determined by the wheel positions and the actuator positions. Use of a single hydraulic actuator would have been considerably simpler, but was not possible because the much larger stroke requirement exceeded the available space under the vehicle.

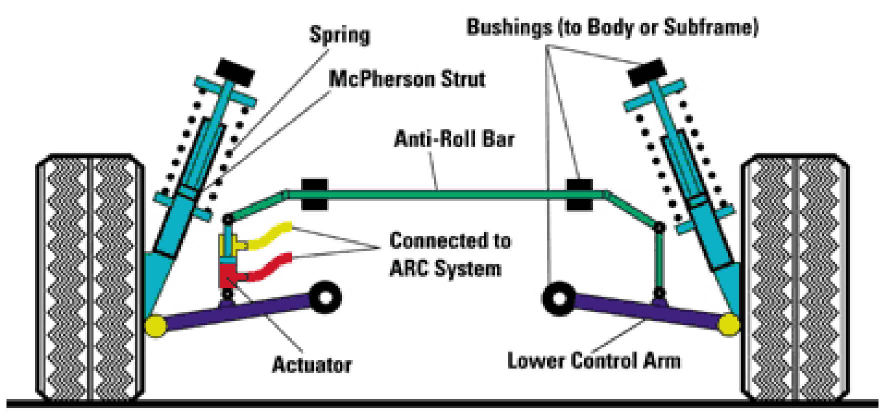

Figure 2.3: Model of the modified trailer suspension, showing the location of the actuators and the anti roll bar:

The worst case transient force is that required to drive the sprung mass sinusoidal at a given frequency with the maximum amplitude of roll angle. Figure 2.4 shows the forces acting on the body in the dynamic case. There are forces from the springs (Fspring), the dampers (Fdamper) and the actuators (FARB).

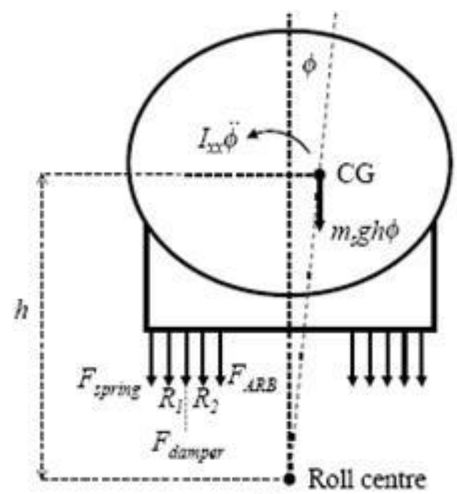

Figure 2.4: Force distribute by spring, damper and actuator