UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SENSITIVITY STUDY OF FRONT SUSPENSION PROPERTIES TOWARD VEHICLE DYNAMIC CHARACTERISTIC USING ADAMS

This report submitted in accordance with requirement of the UniversitiTeknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology (AUTOMOTIVE) with honours.

By

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DEDICATION

I dedicate this report to my beloved mother and sister, Ms LIM AH IM and Ms LOW KAI LAY, whom I deeply indebted with because of their unconditional love and dedication for raise me up from a child to who I was today.

APPROVAL

This is to approve that **LOW KAI ZHONG** with matric number **B071310219** had carried out this project with titled is under supervision and all the works in this project has never been submitted for the award of bachelor degree in UTeM and any other institution of higher education.

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ABSTRAK

Sensitiviti parameter hardpoint penggantungan depan dalam jenis Macpherson akan memberi kesan terhadap prestasi dynamic kenderaan di dalam kereta penumpang. Projek ini menggunakan software Multibody dinamik (MBD) MSC ADAMS untuk menganalisis dan mengetahui parameter hardpoint menjejaskan kepada ciri penggantungan. Ciri-ciri penggantungan adalah seperti perubahan kamber, perubahan caster, roll centre height, dan perubahan toe perlu menganalisis untuk mendapatkan lokasi hardpoint parameter terbaik yang optimum berdasarkan kenderaan sasaran prestasi dynamic. Dua kenderaan utama loadcases dynamic akan menganalisis untuk memahami dynamic kenderaan penalaan ciri bagi penggantungan depan. loadcase pertama adalah Kinetic dan Pematuhan (k & c) analisis bagi penggantungan depan dan loadcase kedua ialah analisis kenderaan penuh. Semua parameter penggantungan hardpoint akan dinilai berdasarkan sasaran dynamic kenderaan untuk kereta. Mulakan dengan model penggantungan depan bina dalam persekitaran Adams software dan kereta akan berada dalam template penggantungan, subsistem dan pemasangan. Dengan menggunakan template penggantungan dan subsistem kita boleh melakukan analisis penggantungan depan (K & C). Ini digunakan untuk mengetahui keputusan dynamic kenderaan untuk sasaran peringkat ke-2. The Kinetic dan Pematuhan (K & C) dan hasil analisis Kenderaan penuh akan dinilai berdasarkan kenderaan standard penumpang dynamic prestasi sasaran kereta.

ABSTRACT

Sensitivity parameter hardpoint of front suspension in Macpherson type will effect towards vehicle dynamic performance in passenger car. This project using Multibody Dynamic (MBD) software MSC ADAMS to analyze and find out responses parameter hardpoint toward suspension characteristic. The suspension characteristic such as camber change, caster change, roll of center height, and toe change need to analyze in order to get the best optimum parameters hardpoint location based on vehicle dynamic performance target. Two major vehicle dynamic loadcases will be analyse to understand the vehicle dynamic tuning characteristic for front suspension. First loadcase is Kinetic and Compliance (k&c) analysis for front suspension and second loadcase is full vehicle analysis. All suspension parameters hardpoint will be evaluated based on vehicle dynamic target for passenger car. Start with front suspension model build in Adams Car environment, it will be in suspension templates, subsystem and assembly. By using the suspension templates and subsystem we can perform front suspension analysis (K&C analysis). This is use to find out the vehicle dynamic results for 2nd tier target. After that perform full vehicle analysis to find out the vehicle dynamic results for 1st tier target. The Kinetic and Compliance (K&C) and Full Vehicle analysis result will be evaluated based on standard vehicle dynamic passenger car target performance. Most affected parameter hardpoint will carry out from this project at the last.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

LCA FRONT	Lower Control Arm Front
LCA OUTER	Lower Control Arm Outer
LCA REAR	Lower Control Arm Rear
TR OUTER	Tie Rod Outer
TR INNER	Tie Rod Inner
STLM	Strut Lower Mount

REFERENCES

Yong Sub Yi, Joonhong Park, and Kyung Jin Hong, 2014, Design Optimization of Suspension Kinematic and Compliance Characteristic, Hyundai Motor

James R Wilde, Gary J Heydinger and Dennis A. Guenther, 2006, ADAMS Simulation of Ride and Handling Performance of the Kinetic Suspension System. The Ohio State University

A.Eskandari, O. Mirzadeh, Sh Azadi, 2006, Optimization of a Mcpherson Suspension System using Design of Experiment Method.

Sergey Abramov, 2009, International Journal of Engineering Systems Modeling and Simulation

Taehyun Shim, Pradheep C Velusamy, 2010, Influence of Suspension Properties on Vehicle Roll Stability, University of Michigan Dearborn.

Wei Yi, Rena Basch, Tom Dalka, 2003, Kinematic Analysis of Brake Induced Vehicle Steering Wheel Vibration.

Parthiv Shah, 2000, Active Suspension Design of Railway Vehicle, University Stuttgart.

Chris Longhurst, 1999, The Suspension Bible.

William Harris, 2004 ,How Car Suspension Work.

Sindha, Jignesh, Basab Chakraborty, 2015, Rigid Body Modeling of Dynamic Stability.

CHAPTER 1
INTRODUCTION

1.0 Introduction

This project is study about the sensitivity of front suspension in Macpherson type parameter towards vehicle dynamic performance in passenger car by using Multibody Dynamic (MBD) software MSC ADAMS. The suspension characteristic such as top mounting point, lower control arm, knuckle and hardpoint need to analyze in order to get the best optimum hardpoint location based on vehicle dynamic performance target.
Two major vehicle dynamic loadcases will be analyzed to understand the vehicle dynamic tuning characteristic for front suspension. First loadcase is Kinetic and Compliance (k&c) analysis for front suspension and second loadcase is full vehicle analysis. All suspension parameter will be evaluated based on vehicle dynamic target for passenger car. Design of Experiment (DOE) will be done and performed on Macpherson suspension hardpoint to study effect of suspension hardpoint toward vehicle dynamic characteristic.

1.1 Background Of The Project

There are many type of software been using in industries to analyze sensitivity of suspension such like Hyperwork, SLARCK, SusProg3D, Working Model, ADAMS and more. ADAMS is phrase of Automated Dynamic Analysis of Mechanical Systems is a multibody dynamics simulation software equipped developed by Mechanical Dynamics Incorporation which then was acquired by MSC Software Corporation. All of

this software is effective helps engineers to study how loads and forces are distributed throughout mechanical systems and the dynamics of moving parts. Multibody dynamic solution improves engineering efficiency and reduces product development costs by enabling early system level design validation. Engineers can manage and evaluate the complex interactions between disciplines including motion, structures, actuation, and controls to better optimize product designs for performance, safety, and comfort. MSC software is popular nonlinear CAE Tool used by automotive industries, aerospace and machine part industries. Some of people still using calculation to analyze suspension sensitivity.

1.2 Problem Statement

Suspension hardpoint is very crucial in suspension tuning parameter. It will effect major changes on suspension tuning during vehicle development. Nowadays it is difficult to identify the suspension tuning parameters in order to get optimum vehicle dynamic performance since a lot hardpoint to tune. Hardpoint is important in analysis of suspension, it is like connection points between lower control arm and wheel alignment parameter. All other hardpoints can be used and decide the parameters of Macpherson suspension and its performance so sensitivity study will be carried.

1.3 Objective

There are some objectives need to achieve in the project:

1. To do the sensitivity analysis such like K&C analysis to find the Tier 2 target and Full Vehicle analysis to find the Tier 1 target on Macpherson front suspension hardpoint parameter.
2. Perform Design of Experiment toward front Macpherson suspension hardpoint by reduce tuning parameters based on vehicle dynamic standard loadcase.

1.4 Scope

The scope of the project is start with front suspension model build in Adams Car environment. There are 3 main part in Adams MSC software which is templates, subsystem and assembly. Suspension templates, suspension subsystem and suspension assembly will be carry out to continue the next step.

The suspension templates and subsystem will be using to perform front suspension analysis which is kinetic and compliance. This kinetic and compliance is use to find out the vehicle dynamic results for 2^{nd} tier target. 2^{nd} tier target is mean the result of kinetic and compliance analysis which using Adams MSC software.

The full vehicle analysis is to find out the vehicle dynamic results for 1^{st} tier target. It only can perform after the result of 2^{nd} tier target been collect. The Kinetic and Compliance (K&C) and Full Vehicle analysis result will be evaluated based on standard vehicle dynamic passenger car target performance. Adams MSC software can more fast build and test functional virtual prototypes of vehicle subsystems and a complete vehicles. Design of Experiment analysis of front suspension Macpherson hardpoint to analysis the sensitivity analysis of hardpoint towards vehicle dynamic performance. Design of Experiment can investigate vehicle designs under different road conditions, performing the same tests vehicle normally run on a test track or in a test lab but in a fraction of time.

1.5 Report Outline

This report is divided into five chapters and each of the chapter is explained briefly as below.

In Chapter 1, this is introduction about the project. In this chapter, background of the project, problem statement, objective and the work scope of the project will be discussed.

In Chapter 2, this is the literature review of the project. In this chapter, all the information about the project will be explained and discussed.

In Chapter 3, is the methodology of the project. In this chapter, will shows how the project is carry on and explain in detail the methods that been used in project.

In Chapter 4 is the project result. This chapter consists of discussion and results of the project.

Chapter 5 is the conclusion of the project. This is the last chapter of the project. The conclusion of the whole project will be discussed in this chapter.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

At this chapter, the related project and information of optimization of a Macpherson suspension kinematic and compliance, design of experiment will be discussed. This project is analyze in order to get the best optimum hardpoint location based on vehicle dynamic performance target.

2.1 Type of suspension

Suspension system is an important component in vehicle to ensure the vehicle anti rollover and stable when turning or cornering. Each type of suspensions has different type sets of limitations and benefits and it will be analyze by manufacturer to fulfill the criteria and perform for all type of suspension.

2.1.1 Active Suspension System

Suspension system in nowadays most of vehicle today is passive type. Chassis of the vehicle is attached to the wheel assemblies through coil springs to protect the vehicle chassis from sudden vertical forces come to the wheel when drive on uneven road (Parthiv Shah, 2000). An active suspension system it mean this suspension has the capability to adjust itself continuously to changing road

condition. It can sense the force applied to the wheel and constantly adjust the mechanical connection between the vehicle chassis and wheel to keep the chassis level optimally and absorb the energy combine with the vertical motion of wheel.

Active suspension system is also known as Computerized Ride Control consist some important component in system to make it function smoothly. Computer or also name as electronic control unit (ECU) use to represent the mind defective though it may be collecting, classifying and analyzing sensor input signal. Adjustable shocks and spring as basic component of suspension, a series of sensor at each wheel of car to sense or feeling the condition of road surface and delivering the data signal go back to ECU. A servo or actuator will set at each shock and spring, it will receive a signal input send by ECU and carry out the command of ECU (Parthiv Shah, 2000).

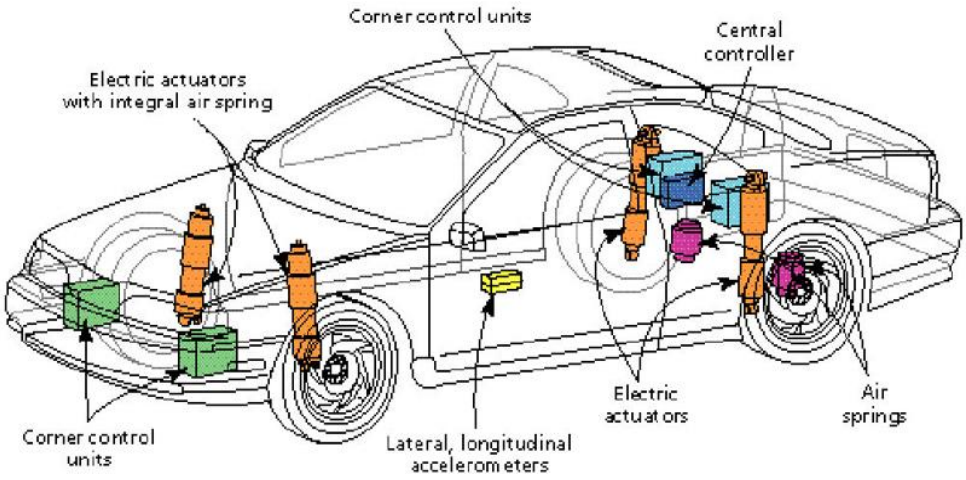

Figure 2.1: Active Suspension System

When a vehicle without active suspension drive in a situation where the vehicle down higher or bob up it will gets a minimum out of control. If with the active suspension the sensor place on right hand front of the car will begin monitor the situation to pick up yaw and transverse body motion send information back to the ECU. Sensor also can sense excessive vertical travel especially in the right front area of the car. A steering angle sensor and rotary

position wheel sensor to confirm the data coming off the other signal output on the car. ECU collect, analyze the data in closely 10ms, and send the output signal to the servo at top the right front coil spring to lift up. For accomplish this engine driven oil pump operating and send additional fluid to the servo which increase spring tension to reduce spring oscillation, yaw, and body roll. At the same time another set of actuators kicks in to temporarily increase the rigidity of the suspension damper on right front and rear corners of the car.

2.1.2 Macpherson Suspension System

Independent Front Suspensions developed by Earle S. MacPherson of General Motors in 1947 is the most generally used front suspension system especially in cars of European origin (William Harris,2004). McPherson strut provides many advantages in package space for transverse engines, and is used generally use for front-wheel-drive cars.. Low unsprung weight is reducing the overall weight of the vehicle to increase the car acceleration and driving more comfortable. Macpherson suspension can directly block vibration from reaching the passenger compartment because it without an upper arm. Macpherson strut suspension systems generally implement to a steering knuckle or a hub carrier and it has two mounting points that connect to the vehicle body. The lower mounting point is connected to a lower control arm or track control arm, and this connection that edict between the longitudinal and lateral orientation of the wheel assembly. The upper mounting point of the knuckle or hub is attached to an assembly part which contains a shock absorber and a coil spring. It is combination include of housing, spring, and damper. It wills extends upward into the unibody shell and bolts to a location that is known as a strut tower. MacPherson strut suspension is the way that axis of the strut also serves as the upper steering pivot as the lower pivot is mounting point at between control or

track arm and the knuckle . Upper pivot point is attached to a tie rod end and also attached to the steering gear.

Advantages of Macpherson struts are related about the relative simplicity of these systems. Macpherson strut suspensions is more less components compare with other suspension, this is mean Macpherson Suspension are less budget to produce than other types of suspension systems and it also save space and provide more room for engine (William Harris,2004). There are also have disadvantages about Macpherson suspension, although it easy to set the suspension geometry when performing repair bolt all the thing in place, the caster and camber will both be correct same simplicity mean that the camber angle necessarily changes when the vertical position of the wheel changes. The net effect seen as possessing inferior handling characteristics to other suspension systems..

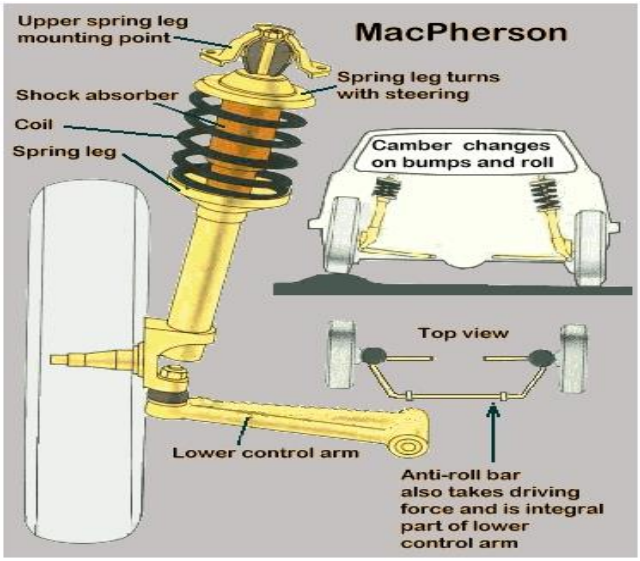

Figure 2.2: Macpherson suspension system

2.1.3 Double Wishbone Suspension System

There are many benefits of double wishbone suspension, one of them is increase of negative chamber result of vertical suspension movement of the upper and lower arms. This is better stability properties for the vehicle tires and also handling performance. Double wishbone suspension is more stable and rigid compare with other steering wheel alignment and type suspension systems are constant when undergo high amounts of stress.

The design of double wishbone suspension typically uses two wishbone shaped arms to locate the wheel. Everyone of wishbone has two mounting positions to the frame and other one at the wheel, bears a shock absorber and a coil spring used to absorb vibrations. Double wishbone suspensions will allow more control over the camber angle of the wheel, it is describes the degree when the wheels tilt in and out. It also help minimize roll and provide for a more consistent steering feel. Base on these characteristics, double wishbone suspension is common used on the front wheels of larger cars. This type of suspension system also proves to be flexible for design engineers like the arms of the system can fixed at different angles to the surface example parameter like camber gain, swing arm length and roll center height can be designed and determined flexibly to fit on different road surface.

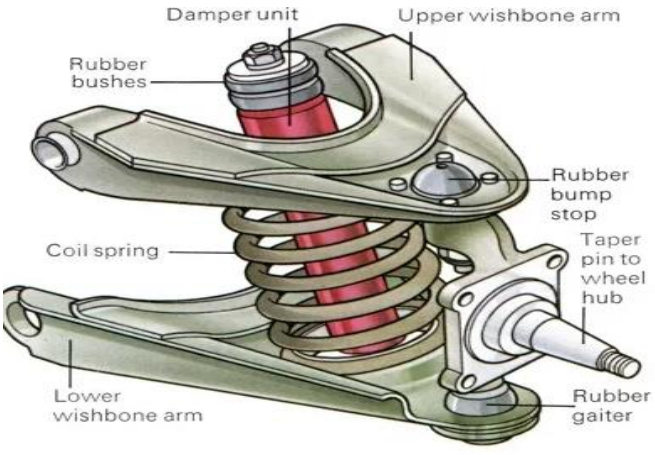

Figure 2.3: Double Wishbone Suspension System

2.2 Performance of Vehicle Dynamic

The vehicle dynamic and performance area is developing innovative technologies for active suspensions, electronic braking system for vehicle. Vehicle dynamics is also involve subjecting dampers, tire systems, steer system and full vehicle to measuring a outputs and set of inputs . This is mean that how a specimen perform in dynamic environment and subsystem or a component influence in test specimen.

2.2.1 Influence of Suspension Properties on Vehicle Rollover

Vehicle roll dynamics are important and influenced by suspension properties such as roll centre height, roll steer, and roll camber (Taehyun Shim 2010). The vehicle rollover can be described as the ratio of moment from lateral and gravitational forces. Gravitational force is always going downward to hold the vehicle against on the ground. Lateral force is come from the lateral acceleration when cornering and at the center of mass on the ground, resulting in a moment on the vehicle that try to roll it over. If the lateral acceleration is large than the gravitational forces, the resultant force will flow outside of the outer wheel and cause the vehicle roll.

The rollover is defined by the peak value of lateral acceleration that is needed to bring the vehicle to the point of initiating roll (Sindha 2015). Under the action of a lateral acceleration, the sprung mass rolls about the roll center of the suspension system. This motion is can reduce by the roll of stiffness of suspension system, the lateral shift of center of mass places it closer to outside wheel then reduce the lever arm available for the gravitational force resisting rollover. There some system use to reduce the rollover happen, roll stability control use to reduce the risk of vehicle rollover in ultimate cornering. This is system effective for a vehicle with a high centre of gravity because more easy to rollover.

Roll stability control is using a gyroscopic sensor and electronic stability control system (ECS) to limit vehicle roll by braking one or more wheel and reducing engine power. Beside that the curve control system helps prevent loss of control of a vehicle on a curve. When curve control system sense the vehicle move to a curve too quickly it will automatically control to slows the vehicle speed by reducing engine power and control brake servo applies braking to the four wheels.

2.2.2 Influence of Suspension on Handling and Ride

Ride and handling main characteristics of a vehicle is on the characteristic of the tires. Tires absorb the input force and disturbances from the road and final link in the driver chain of output commands. Tires basic characteristics are handled by the system of dampers, linkages, and springs that control the way when tires move counter the force and disturbances (Sergey Abramov.2009). Ride comfort is affected by a variety of factors like body booming, high frequency vibration, body roll and pitch. Ride quality is link with the vehicle response to bumps is a factor of the relatively low bounce and rebound movements of the suspension system.

Damping of suspension is important effect in ride and handling of a vehicle. The relative vertical and roll damping properties of the suspension form are calculated constant area damping orifices. Hydraulic suspension damper reduce energy through pressure drop across the orifices or valve. The damper yield high viscous damping coefficient at medium and high velocity to achieve a better compromise between vehicle ride and handling.

Spring element of suspension is use to store elastic energy pre unit of weight. Factor on choose spring is depend on the relationship between the deflection and load which is called spring rate. Soft spring suspension can provide a comfortable ride on a smooth road beside that spring must be enough