Steering system and suspension design mechanics essay

The aim of this project is to work with a project team to design, build and optimize the running of a Formula SAE-A racecar, with particular interest in the Steering and Suspension systems. The Formula SAE-A project team aims to produce a competitive racecar that will compete in the Formula SAE-A competition in December.

To achieve this I was required to, research the important aspects of steering and suspension systems used frequently in a nonprofessional racecar and select a suitable steering and suspension system that is within the motorsport teams limits. This project includes suggestions for the design and construction of these systems, the installing and optimising(or tuning) the steering and suspension systems and future recommendations

to provide the most cornering and handling ability.

Identifying the critical areas that are important for competitive steering and suspension

systems, I can improve the effective handling and cornering capability of the racecar.

Improving the handling and cornering power of the racecar will allow faster speeds into

and exits out of corners, which will result in quicker lap times, better performance and

higher overall standing in the 2006 FSAE-A competition.

Adhering to the rules and regulations for the 2006 FSAE-A competition I aim to select

suitable systems that are within the project teams limits by considering the financial

cost versus benefit or performance to the car, complexity and time to design and

1. 1 Cornering Ability and Handling 2

manufacture of each system.

Critically analysing the 2005 teams racecar enables me to evaluate the cars steering and

suspension setup performance and find any flaws or ways to improve them. This will

give me a better understanding of the steering and suspension systems and how to find

the optimum settings to perform with the 2006 car at the FSAE-A competition. Using

a suspension geometry computer program developed by Wm. C. Mitchell software, I

can model the 2005 teams racecar to compare the accuracy of the program, and then

apply the program to optimise the 2006 racecar.

The ideal outcome of this project will see that this years FSAE-A racecar have a working

and well-tuned or optimised steering and suspension system that has high cornering

ability and handling. Most of this projects work will become evident once we have

manufactured our design and are able to test the car by running it on a test-track. If

all things go to plan, I should be able to make small adjustments to improve and finally

optimize the handling and cornering ability of the car which will be paramount to the

performance at the FSAE-A competition.

1. 1 Cornering Ability and Handling

The cornering ability and handling of the racecar is very important to the overall

performance of the racecar. Having excellent acceleration and braking power is good

but without sufficient cornering ability and handling, the racecar will not be able to

use the full potential and is more likely to run off the racetrack than take a podium

position. Cornering ability and handling will be discussed in detail and how the steering

and suspension systems affect it.

1. 2 Explanation and definition of terminology 3
1. 2 Explanation and definition of terminology
Here is a number of terms and names that will be used in this dissertation to avoid

confusion with other names and meanings.

Ackerman – Is both a principle and definition, where the principle is that the extended

axis of the steering arms projected rearward meet at the centre of the rear axle

(shown in figure 1. 1). This allows the tyres to traverse an arc without skidding,

which would otherwise oppose the steering forces making it harder to steer. The

definition is described as the difference in the angle of the front tyres when turned.

This dissertation will only refer to Ackerman as the principle from herein.

Camber – Is the angle between the vertical plane and the centre angle of the

tyres

(shown in fig 1. 2), which can be positive or negative. This changes the size

and

shape of the tyres contact patch during a corner which in turn affects the

amount

of lateral acceleration or force it can produce (cornering and handling

ability). A

small amount of negative camber is ideal (around 1. 5 degrees) to induce

camber

thrust and ensure a good contact patch during cornering (smith. C. 2004).

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Camber Gain – Or the rate of camber change in roll (or as the chassis rotates

laterally).

Caster – Is the angle between the steering axis and the vertical from the side

plane

(see fig 1. 3). Positive caster improves straight line stability but makes it

slightly

more difficult to steer, while negative makes it easier to steer with less

stability.

Jacking – Is an upwards reaction force generated by the tyres when the

racecar is

accelerated during cornering and has its roll centre above ground level.

Where

the upwards force on the outside tyre is greater than the inner tyre having a

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net resultant force that lifts or Jacks the sprung mass. This is unwanted and

unsettling to the driver and should be avoided.

The roll centre – Indicates the point at which the chassis rotates (at the front

and

rear respectfully) during lateral acceleration. The two moment arms between

the

roll centre, the CG and the ground plane determine the racecar's sensitivity

to

lateral acceleration by the production of rollover movements and jacking

(Smith.

C, 2000).

The roll axis – Is the straight line joining the roll centre's of the front and rear

tyres

The roll moment – Is the distance between the roll centre and the mass concentration

at the front or rear of the car. The mass concentration is the equivalent mass or

point of the CG if it were split into 2 points, one front and rear.

Steering Axis Inclination and Scrub Radius

Steering Axis Inclination – or Kingpin Axis, is the angle between the vertical and

the steering axis (figure 1. 4). This helps the car to exit a corner by naturally

trying to align the wheels back to centre. The SAI works with caster to allow

more directional stability but less effort on steering (more sai and less caster).

Scrub Radius – Is the pivot point for the tyres footprint or the distance between the

centre of the contact patch, to the extended SAI to the ground (figure 1. 4). This

allows more feel in the steering, a little is good, too much can be detrimental due

to the increased steering effort for the driver.

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Slip angles – Are the angles between the direction that the tyres are facing,

and the

direction that the tyres want to go. Deformation is due to the elastic nature

of

rubber when a vertical load is applied. This will be explained in detail in

Chapter

2 and its effect on cornering and handling.

1. 3 Overview of the Dissertation

This dissertation is organized as follows:

Chapter 2 Discusses cornering and handling of a FSAE-A racecar and

describes various

steering and suspension systems.

Chapter 3 Explains the rules and regulations of the FSAE-A competition and

how it

affects the steering and suspension systems.

Chapter 4 Introduces Wm. C. Mitchell's suspension geometry software,

describes its

uses and strengths for this project and how it will be used to improve the

steering

and suspension systems.

Chapter 5 Describes the analysis of the 2005 FSAE-A racecar and documenting areas

that can be improved and implemented into the 2006 car.

Chapter 6 Describes the analysis of the 2006 racecar and recommendations for improving

the cornering and handling ability.

Chapter 7 Discusses testing methods and ways to document and record actual performance

of the racecar, followed by processes for optimisation of the steering

and suspension systems for the best cornering ability and handling.

Chapter 8 Outlines the project's achievements, findings and future recommendations.

Chapter 2
Steering and Suspension Systems for a FSAE-A Racecar
2. 1 Chapter Overview
This chapter discusses the steering and suspension systems that are commonly used

in cars on the road and in professional racing, their benefits and limitations, the ease

of manufacture and complexity of design. This chapter also discusses cornering and

handling in detail and how the steering and suspension can improve it's cornering and

handling ability.

2. 2 Cornering and Handling

Handling defines the racecars ability to maneuver around a corner at maximum speed

without losing traction. C. Smith (1978) remarks that being able to travel around a

corner faster reduces the overall lap time on a circuit for 2 reasons. First is simply

that the car traverses the distance in less time, secondly, if the car exits the corner at a

faster speed, there will be no time lost from having to accelerate from a slower speed.

Smith (1978) also says that the factors that determine the cornering power of a racecar

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include the cornering capacity of the tires, which is influenced by:

Vehicle gross weight

Vehicle downforce

Height of the vehicle's centre of gravity

Vehicle load transfer characteristics

Suspension Geometry

Size and characteristics of the tyres

So you can understand, the tyres are arguably one of the most important parts of

the racecar because all the moments and forces that the car undergoes is transmitted

through the tyres. The acceleration and direction of the car is passed through the small

footprints or contact patches of each tyre. Understanding what happens here will help

to get the most out of both the tyres and racecar's handling ability (Smith, C. 1978).

2. 2. 1 Tyres and slip angles

The tyres ability to grip the road is a combination of vertical load applied to the tyre,

the coefficient of friction between the tyre and the road, adhesion between the road

surface and tyre, and slip angles developed between the tyre and direction

of travel.

The vertical load that is imposed on each tyre is changing continuously on a

racecar

maneuvering around a racetrack due to the load transfer from acceleration,

deceleration

and cornering. As the racecar travels around a corner, the tyres are subject

to forces

which result in deformation in the compound that the tyre is made of, this

elastic

deformation results in the contact patch pointing in a different direction to

the angle

of the tyre (Smith, C. 1978).

Shows the deformation of the tyre compound in the contact patch and the

slip angle developed. The path of the rolling tyre defines the actual direction

of the

tyre as it continues around the corner. There is a relationship between the

slip angles

and the potential grip that the tyre has to the road. Some tyre data has

shown that

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Shows the generated slip angles in the tyre contact patch

as slip angles increase, the lateral or cornering force increases up to a maximum which

then either begins to drop or plateaus then drops, usually sliding occurs soon after the

drop in force. The flat portion of the curve at or near the maximum is the optimum

range of tyre grip that experienced drivers remain in to maximize the cars cornering

potential.

shows the relationship between tyre grip and the developed slip angles.

shows the relationship between tyre grip and developed slip angles, picture

from http://www. donpalmer. co. uk/cchandbook/modelgrip. htm

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2. 2. 2 Factors influencing tyre cornering capacity

The other factors as mentioned before, vehicle gross weight, downforce, height of the

CG, tyre size and characteristics, suspension geometry and load transfer characteristics,

all can be factored into the design or used to improve cornering and handling. The

cornering force is proportional to the increase of the vehicle gross weight and generated

downforce from wings or aerofoils. The increased pressure on the contact patch generates

a higher lateral force component (Smith, C. 1978). The height of the vehicle's

centre of gravity from the ground affects the moment between the vertical force on the

tyre and the CG, this will affect the lateral load transfer during a corner.

The lateral load transfer changes the vertical loads from one wheel to another due to the

CG tendency to move sideways during a corner, which will decrease the total amount

of cornering force generated from the tyres. For example, a 400kg car with a 50-50

weight distribution front to rear will have 100kg vertical weights at the two front tyres.

Assuming the CG height is 250mm above the ground, the track width is 1300mm and

during a corner the car is subject to a cornering acceleration of 1. 4g's we can determine

the load transfer.

LoadT ransfer =

1. 4 × 200kg × 0. 25

1. 3

= 53. 85kg

So this gives us 46. 15kg on one side and 153. 85kg on the other and is a 53. 85% load

transfer to the outer wheel. Obtaining tyre data in the form of Tyre cornering force

versus Vertical load will allow us to determine the total cornering force with this load

transfer, however getting the tyre data is difficult. Generally the tyre data is curved with

less tyre cornering force as vertical load increases, so measuring the data of each vertical

load and summing together will be less than the equal load distribution. Reducing the

load transfer is done by lowering the height of the CG and widening the track width

which will improve cornering ability.

The suspension geometry determines the location of the instantaneous centres and

roll centres of the racecar, these control how much the chassis rolls or pitches during

cornering and accelleration, which moves the CG and hence affects the lateral load

transfer.

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During roll, the suspension geometry also controls the amount of camber gain in the

wheels during a corner, the change in camber affects the contact patch (increase or

decrease in proportion) which changes the cornering capacity of the tyres. Ensuring

that an optimum contact patch is maintained through the control of camber gain and

good roll centre location is key to good handling and cornering.

2. 3 Steering Systems

Common types of steering systems are:

Rack and Pinion – basic steering system

Recirculating Ball Bearing – more complex system

Power Steering – fluid assisted steering

2. 3. 1 Rack and Pinion

The rack and pinion steering system is a simple, cheap and relatively easy system to

implement. It comprises of a rack, or toothed bar/rod which slides left and right due to

the rotation of a pinion gear that sits on the teeth (Fig 2. 3). The steering wheel turns

the steering shaft which rotates the pinion gear, resulting in the rack pushing/pulling

the steering rods. The rods are attached to the wheel hubs which turn the wheels to

the desired angle (Gilles, T. 2005).

The most difficult parts to design or manufacture are the pinion and the rack, the pinion

defines the turning rate of the steering wheel which affects the

responsiveness of the

steering. The rack need to have hardened teeth which could be difficult to

manufacture

to some groups or would involve a significant cost to have it done. Besides

these two

parts the rest of the system is relatively simple, as a whole the rack and

pinion setup

is a cheap and common system that is reliable and resiliant.

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2. 3. 2 Recirculating Ball Bearing

A typical Recirculating ball-bearing steering system uses a worm gear to shift

ball

bearings that are located within a channel such that when moved, pushes or

pulls the

housing in which they sit. The housing has teeth located on the outside

which are in

line with a sector gear that rotates a pitman arm (Fig 2. 4). The pitman arm

is attached

with the track and tie rods, which aligns the wheels. This system can also be

described

as a parallelogram steering linkage system in which the linkages trace a

parallelogram

(Gilles, T. 2005).

Figure 2. 4: Recirculating ball bearing steering, picture from www.

imperialclub. com/

Repair/Steering/terms. htm

A Recirculating Ball Bearing can also be used in a similar setup to aRrack and

Pinion

gear system, where the recirculating ball bearing housing replaces the pinion

gear with

a sector gear that pushes/pulls the rack to align the wheels. The recirculating

ball

2. 3 Steering Systems 13
bearing system is significantly heavier than the rack and pinion system, due

to the

extra linkages, housing and gears. Friction needs to be managed in the

design stage,

i. e. including grease input points, dust covers etc. However the Recirculating

ball

bearing steering provides more sensitivity to the steering and minimum

slack or ' loose

feel' in the steering wheel. Costing is also increased due to the extra

material and the

complexity of design makes the recirculating ball bearing system less

attractive.

2. 3. 3 Power Steering

Power steering systems are the same systems as rack and pinion and

recirculating

ball-bearing but with a significant modification. In a rack and pinion power

steering

system, the rack contains a cylinder with a piston inside it, driven by fluid

supplied by

a pump (see Figure 2. 5). The fluid lines run to a rotary valve controlled by

the steering

shaft which determines the sides of the piston that the high pressure fluid

acts on.

This pressure assists the steering action which requires less force to rotate

the steering

wheel. Similar to the rack and pinion power steering, the recirculating ball

housing is

assisted by the pressure respectively in the ball-bearing steering (Gilles, T.

2005).

Rack and Pinion power steering, picture adapded from www. cars. com/

carsapp/boston/? srv= parser&act= display&tf=/advice/caradviser/steering_

fluid. tmpl

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2. 4 Suspension Systems

There are two common types of suspension systems used frequently today,

dependant

and independant systems. The various types of both are similar but have

their differences

and functions. Some of these sytems are described below.

2. 4. 1 Dependant Suspension Systems

Solid or Beam Axle

Panhard Rod

Watts Linkage

Dependant suspension systems are variations of a simple beam axle that

holds the

wheels parallel with each other. So when the vertical angle of one wheel

(camber)

changes, the opposite wheel also changes (Gilles, T. 2005). Examples of the

Panhard

Rod and the Watts Linkage are shown in Figures 2. 6 and 2. 7, these types of suspension

are generally different ways of attatching the solid axle to the chassis.

2. 4. 2 Independant Suspension Systems

Double Wishbone, A-Arm or Four-Bar link

MacPherson Strut

Multi-link

2. 4 Suspension Systems 15

Watts linkage suspension.

Independent suspension systems allow the wheels to move independently of each other,

e. g. if one wheel were to move up or down, the other would not be affected directly. It is

common for racecars to have all four wheels with independent suspension as this usually

provides the most customizable setup options to maximize the handling potential of

the racecar.

Double wishbone suspension systems are also known as double A-Arm or Four-Bar link

systems. They all comprise of equal or unequal parallel links from the chassis to the

wheel hub, with the shock absorbers configured in a Push or Pull rod setup, as Figure

2. 8 illustrates.

Unparallel and Unequal double wishbone suspension with Push or Pull rod

shock absorber setup.

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The MacPherson strut suspension system (Figure 2. 9) is very popular with passenger

cars and some sports models since it is a relatively cheap system to produce that provides

reasonable camber control (Smith. C, 1978). The MacPherson strut suspension

is good for everyday commuting but does not provide sufficient stiffness to avoid movement

within the components (compliance or slack) and would not fit comfortably with

wide tyres (Smith. C, 1978). Multi link suspension systems are simply Four-Bar link

systems with one or more extra links to attain extra control.

MacPherson strut suspension, from www. autozine. org/technical_school/

suspension/tech_suspension2. htm

The objective of the independent suspension is to provide enough vertical

wheel movement

to absorb surface bumps and compensate for the accelerations of the sprung

mass,

prevent changes in the distance between tyres (static toe) as they are

moving, control

the change of wheel camber angle and change of track distance with the

wheel and/or

sprung mass movement, and to ultimately allow the most grip or traction

available out

of the tyres while minimising weight and maximising stiffness in the links

(Smith, C.

1978).

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2. 5 Chapter Summary

Having discussed the cornering and handling ability in a Formula SAE-A

racecar and

what factors can influence the performance, helps to have an understanding

of what

is happening when a racecar traverses around a corner. With this in mind we

can

apply this knowledge into the design to maximise the cornering and handling

ability

of the racecar. Also selecting an appropriate steering and suspension system

that will

provide the best cornering and handling but also takes into account the

motorsport

teams' resources (time, materials and complexity of design).

Chapter 3
Rules and Regulations of the FSAE-A Competition
3. 1 Chapter Overview
This chapter covers the rules and regulations that will affect the steering and

suspension

sytems. Starting with the more specific rules that affect the steering and

suspension

systems, then moving into the general rules and regulations like material

strength.

These rules and regulations have been put into the competition to give the

entry teams

maximum design flexibility and the freedom to express creativity, but also to ensure

that a safe and working car that minimises chances of damage and injury.

3. 2 Steering Requirements

The specific steering system rules and requirements are as follows:

The steering must affect at least two wheels

The steering system must have positive steering stops that prevent the steering

linkages from locking up.

3. 3 Suspension Requirements 19

Free play is limited to 7 degrees measured at the steering wheel.

Steering must be mechanically connected to the wheels i. e. steer by wire prohibited

These requirements do not severely limit the steering system design at all as for most

of the previously mentioned systems, none of which include steer by wire and all affect

at least 2 wheels. The rules that need to be kept and monitored is the free play in the

steering wheel and steering stops, otherwise the design is virtually open.

3. 3 Suspension Requirements

The rules state that the car must have a fully operational suspension system with

springs and shock absorbers, front and rear, with a minimum useable wheel travel of

50. 8mm (2 inches), 25. 4mm (1 inch) in jounce and rebound with the driver seated.

So the rules again do not restrict the specific suspension system but merely sets a

benchmark that it must perform to.

3. 4 Other Requirements

Other requirements set out in the rules define that the wheelbase must be of at least

1525mm (60inches) and that the smaller track must be no less than 75% of the larger

track. The minimum material must be; either round mild or alloy, steel tubing (min

0. 1% carbon) with minimum dimensions as outlined in table 3. 3. 3. 1 in the FSAE rules

handbook; or an approved alternatice material that is tested and proved to meet the

alternative material guidelines in section 3. 3. 3. 2 of the FSAE rules

handbook.

The wheelbase requirement affects the suspension geometry design, setting

a minimum

length for the suspension linkages.

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3. 5 Chapter Summary

Knowing and understanding the requirements and rules set out by the

Formula SAE

competition provides a starting point for our design, also talking with the

previous team

and the performance will help to identify areas needing improvement and

investigaiton.

Once finding suffcent information a start can be made to get the ball rolling

on design

and construction of the steering and suspension systems.

Chapter 4

WinGeo3 Suspension Geometry Program

4. 1 Chapter Overview

This chapter introduces Wm. C Mitchell's suspension geometry software,

Racing by

the Numbers and shows its most useful power of calculation and display of steering

and suspension geometry of any four wheel vehicle. The information it can tell us will

greatly improve the time taken to analyse steering and suspension set-up and will allow

fast optimisation when the time comes to testing.

4. 2 WinGeo3 Geometry Program

The steering and suspension geometry can be modeled on Wm. C. Mitchells software

which is quicker than manually measuring all the various important values repeatedly

for the various settings you wish to try during testing. This enables a comparison

with the originally intended design parameters of the 2005 racecar and an indication

of how well the car will react while cornering. It also allows a comparison of the initial

2006 car's design and actual geometry after construction and allows us to optimise

the geometry to provide the best cornering and handling ability of the

racecar. By

4. 3 Set-up and initial measurements 22

measuring the data and entering into Wm. C. Mitchell's software, we can

critically

analyse the racecar with regard to the handling and cornering

characteristics. The

software requires actual measurements taken from the car which will be

done and

recorded according to the geometry software requirements.

Once recording all the information that the software needs, we can analyse

the way the

steering and suspension reacts with the chassis. Moving up or down (ride) or

rotating

(roll) we are able to observe the change in camber, steering angles and

caster at each

of those changes. This is useful since during a corner, we may model the

changes that

the chassis will go and can see the result on the tyres (and contact patch)

and get an

indication of how well it will perform.

Wm. C. Mitchell's software can also be used to aid in the design of steering and

suspension systems, through its design and build functions you may specify various

values and the software will convert it into the required lengths of the arms and rods.

4. 3 Set-up and initial measurements

I strongly recommend allowing at least half a day to measure up a car for the first time

and someone to help. It will save alot of time that would otherwise be lost dropping

things, re-setting the origins and other fiddly jobs that are not normally accounted for.

Once installing the program, printing out some forms will make things much easier for

entering information into the program once the measurements have been taken, as the

forms sets out the required information neatly and in similar format to the program

screen.

Open the geometry program and from the help menu open quick start. The help tree

is on the left side column, from there open the Files menu and then Blank Forms,

here is all the blank forms that is needed. Click on Blank forms: Measuring cars for

some general information and hints, for a double wishbone suspension with a push/pull

damping system, click on the Blank forms: Double A-arm and Rocker Arm option and

print. Also click on Blank forms: Pull-rod / Push-rod form, Blank forms: Auxiliary

points, and Blank forms: Swaybar form and print them all out. These all will be

4. 3 Set-up and initial measurements 23
sufficient for the front suspension and rear (remember to print a second batch of forms

for the rear) unless you have a control arm / panhard rod rearaxle suspension setup,

for which there is a seperate form.

First you need to make sure that the car is set up already with the correct alignment

and on a flat surface as it would on the racetrack. Ensure that access to the suspension

points is possible and that they are locked in place so they do not move if you lean

on the car (within reason). Then determine a baseline or origin accurately and place

strings on the surface plate or flat floor or tie to appropriate point, to represent the

centerlines of the car (front to back, side to side).

Once an Origin for each Axis has been made, where the X-Axis is the fore-aft longitudinal

dimension (front to rear of the car). The Y-Axis is the lateral dimension, or left

and right sides of the car (drivers side – passenger side) and the Z-Axis is the vertical

dimension from the ground up. Care must be taken when selecting an origin due to

common suspension adjustments, such as changing caster, can move the tire contact

patch. Each such change requires a careful remeasurement (or re-calculation).

When the car is ready to be measured, follow these steps:

Measure the track width of the front and rear tyres by taking the centre points

of each tyre as low to the ground as reasonable, the WinGeo3 program measures

track at ground level at the center of the tire contact patch. The easiest way is

to measure to the middle of the tire, but this can be misleading if the tire has

significant static camber, so as long as you are aware of the settings you should

be fine.

Measure the static toe for the front tyres while measuring the track at the front

and do a quick calculation of the static angle pointing inwards or outwards that