Design and Analysis of Double Wishbone Suspension for Formula Student Car

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Abstract - The objective of the paper is to design and analyze the suspension for a formula student car. The aim of this project is to design, and build the suspension system for the 2021 Car. To be able to design a suspension system background research was performed to understand the suspension geometry. The suspension type used will be Unequal double wishbone.

The suspension system is an important part of the formula vehicle. It should be reliable and compact as well as provide better handling to the car. The suspension deals with a lot of forces when cornering, acceleration, braking and bump conditions applied during dynamic situations. This paper presents a methodology to design and build a suspension system for an FSAE car.

***Key Words*: Suspension, Double wishbone, Dynamic, FSAE**

1. INTRODUCTION

What is Suspension System?

The Suspension system is a device connecting the body with wheels. The motion between the wheels and body is constrained by the suspension. All kinds of forces and movements between the wheels and the ground pass to the body through the suspension. The design of suspension system is an important part of the overall vehicle design which determines performance of the car.

Suspension should have following requirements

1) It must have Shock Absorbers.

2) Suspension travel is not less than 50mm

3) Must have appropriate vibration ability.

4) Ensure the car has good handling and stability performance.

4) It must be light in weight and strong.

A proper suspension helps maintain the car at the same level. The double wishbone type provides an aerodynamic benefit from the design of the A-arms and the push rod. The lower centre of gravity makes the vehicle better for cornering stability. The suspension maintains a uniform contact tyre patch on the road or track surface. It allows for better steering control of the vehicle and aids in turning precision. An ideal and well designed suspension provides an adequate force feedback to the driver about the elevation and bumps changes on the road surface and grip condition. The suspension must provide less body roll and precision with better front end grip for the wheels. It should help with good rear stability when accelerating out off turns thus avoiding a twitchy or oversteer corner exit. Suspension should be shaped to suit the concerns in vehicle design in the areas of weight distribution. An ideal suspension has the ability to move components closer to the ground and lower the chassis of the vehicle.

2. PROBLEM STATEMENT

In FSAE competition, the events focuses on the performance of the vehicle as well as on the design itself. The competition assumes the students as a fiction company who is set to build a prototype formula race car within the provided rule set. This prototype is expected to go on a production and assumed to be marketed towards weekend racing. The design is also prioritized compared to the performance during judging and scoring. In previous FSAE events from our college, the suspension design lacked in a solid methodology that will require time and resources.

The objective of this senior project is to design and optimize the suspension for FSAE and develop a process that future teams can follow. Using new research and analysis methods the suspension for the same events will be developed to provide a robust and stable design for the dynamic situations in the competition.

The competition provides a challenge for engineering students to develop various engineering skills. The events require them to be placed well in two different categories; Static testing, where design is judged, and dynamic testing, where the car in motion and its performance is judged. Teams get a global exposure for their respective university from the automotive industry as well as good relationships with companies which eventually lead to increase in job placement.

In order to place well, the vehicle must be designed with good engineering practice and must perform well. Since the event is an autocross event, which favors cornering over top speed, this means having a suspension system that can maximize the performance of the tires in contact with the road.

3. FUNDAMENTAL CONCEPTS

1. Kingpin Inclination

Kingpin inclination typically known as "Steering axis inclination" is that the angle from vertical to the steering axis of the tire between the higher and lower ball joint viewed from the front. Kingpin inclination angle affects the raise of the wheel throughout cornering because it lifts the vehicle as it corners and makes the wheels want to steer straight as the weight of the car returns the steering to centre. The kingpin inclination angle conjointly affects the camber angle of the wheels as they turn and the wheel can gain positive camber. This may be helpful to the handling of the car when creating tight turns.

2. Caster

The angle of the steering axis between the higher and lower ball joints viewed from the side is often referred to as Caster angle. With a positive caster angle the contact patch of the tire to the bottom referred to as Mechanical path, is behind the steering axis this creates a torque on the steering axis because the force on this point acts perpendicular to the steering axis and makes the wheel want to steer straight. With a negative caster angle, the contact point of the tire is in front of the steering axis. The results of a negative caster angle are opposite to a positive caster angle because the forces performing on the contact patch needs to turn the wheel when cornering creating the vehicle unstable.

3. Camber

The angle of the wheel in or outward several to vertical viewed from the front is named a camber angle and can turn out lateral force called camber force. Positive camber is when the top of the wheel is tilted outwards from the vehicle and negative angle when the wheel is tilted in towards the vehicle. Race cars sometimes have a negative camber to extend high-speed stability and tire grip once cornering because it compensates for the positive camber gain as a results of the Kingpin Inclination angle and maximizes the contact between the tire and also the road.

4. Scrub Radius

Scrub radius is the distance from the steering axis to the middle of the contact patch of the tire. The scrub radius creates a lever arm on the steering axis that longitudinal forces act on and analyzing on the tire grip a moment is often translated to the steering. Scrub radius is outlined as positive and negative relying if it's on the within or outside of the centre line of the tire. The scrub radius will have an effect on the toe of the vehicle due to the longitudinal forces that act on the scrub radius arm.

5. Wheel Rate

The wheel rate of a vehicle is a very important thing and about fine calibration of suspension properties and a change in wheel rate changes the tire force at the bottom, the lateral force changes to the grip and handling of the vehicle. Wheel rate is the force per unit for vertical displacement of the centre of the wheel and is the spring rate measured at the wheel centre rather than activity at the spring. The spring rate is calculated by the force needed to compress the spring divided by the deflection.

$$Ks = F/l$$

Where,
Ks = spring ratio (N/m)
F = the force acting on the spring (N)
L = spring displacement (m)

6. Roll Rate

Roll rate is known as the moment resisting body roll, per degree of body roll from the lateral force. The resistance to body roll will be provided by anti-roll bars, track dimension and suspension setup, the peak of the centre of gravity (CG) and also the distance to the roll centre affects the roll rate of the automobile, an automobile with a high CG would force stiffer suspension or anti-roll Bar to complete the higher CG.

7. Unsprung Weight

The unsprung weight of a vehicle is the fraction of the overall weight that's not supported by the suspension springs and can typically contain the wheels, tires, hubs, uprights, brakes (if mounted outside the car's chassis), and lastly, roughly 50 percent of the burden cause of drive shafts, springs and shocks as well as the suspension links.

8. Sprung Weight

This is essentially the opposite of the earlier mentioned definition. It states that the sprung weight is the portion of total automotive weight that is supported by the suspension springs. This weight is way larger than the unsprung weight because it consists of weight from the bulk of automotive elements which might embody the chassis, engine, driver, fuel, shell and different elements housed within the chassis.

9. Dynamics Load Transfer

It is the load transferred from one wheel to another due to the moments about the vehicle's centre of gravity or its roll centers as the vehicle is accelerated in one sense or another.

10. Longitudinal Load Transfer

Longitudinal load transfer is that, the results of the cars mass moving from the front of the vehicle to the rear, or the rear to the front when fast or braking severally.

11. Lateral Load Transfer

The lateral load transfer by a vehicle is the same principle like the longitudinal transfer but revolved ninety degrees such load is either transferred from the right to the left under a left hand corner and from the left to the right in a right hand corner.

12. Dive and Squat

Dive and squat are essentially a similar construct except reversed. Dive is wherever the side of the dips down below braking because of the longitudinal weight transfer from the rear of the automotive to the front performing on the front springs. Squat is wherever the rear springs square measure compressed because of longitudinal weight transfer, from the front of the automotive to the rear, that in result causes the top of the vehicle to depress towards the bottom plane.

4. DESIGN PROCEDURE

Designing of suspension system is done in following parts. The design of the component parts and after that testing of components. Following steps were used while designing the system.

Part A: Basic designing

- Vehicle parameters- wheelbase, track width, tyre, wheels and other parameters.
- Designing of knuckle along with wishbone.
- Designing of Suspension Geometry.

Part B: Testing of designed components and suspension geometry

- Using software like ADAMS, ANSYS, SOLIDWORKS and OPTIMUM G to check the simulation practicality and of system.
- Testing of vehicle by actually driving after the assembly of the system on vehicle.

Analyze and study double wishbone type suspension.

Following are the two different types of Double wishbone suspension systems:-

Pull Rod Suspension:-

1. Gives higher Centre of Gravity.

2. Less Stable at high speed.

3. Assembly of bell crank is quite complex.

4. Aesthetically looks average.

5. Mountings are compact.

Push Rod Suspension:-

1. Centre of gravity is lower.

2. More stable at high speeds.

3. Assembly of bell Crank is easy.

4. Aesthetically looks attractive.

5. Mounting is easy.

By comparing all of the above properties of both geometries. Selection of the Pushrod suspension system is decided as manufacturing concern and also mountings of chassis are easy.

Determine vehicle track width with respect to the chassis dimensions.

Track width will be 75% to 80 % of the wheelbase i.e. 60 inches Minimum (1.16205m= 45.75 inch, 1.23952= 48.8 inch).

(Note: Rear track should be little wider then front track (the rear track of a FSAE Car is usually a bit wider than the front. This makes it easier for the driver to not hit cones with the inner rear wheel in tight turns.)

Determine tyre size and rim diameter.

The tyre size available in the market for FSAE cars were of 16" and 18". The one we chose is of 16" due to its low cost, better availability and its performance.

Determine suspension geometry.

- Camber Angle – According to the instruction by the tyre Manufacturer.
- Vertical Centre of Gravity – It should be low enough so that the Vehicle passes the 60° tilt test and 1.5G cornering.
- Roll centre Height – In front it should not exceed 15% of vertical Centre of Gravity (CG) and in rear it should not exceed 30% of vertical CG
- A-arm Links –50% to 80% of the length of the upper A-arm.
- The longer lower A-arm helps in easy adjustment of camber angle as per needs.
- King Pin Inclination –It should be in the range of 5° to 15°.
- Caster angle –Its should be 5° to 7° for mid range and up to 15° toward the height end.
- Suspension travel should be a minimum of 2 inches.

- Suspension linkage ratio considered should be of 2 inch of spring travel for 1 inch of wheel travel.
- Location of CG is 8.81 inches.
- Weight Distribution during vehicle braking.
- Vertical Forces on Front Tyres (Ff) = 286.98 kgs (632.703 lbs)
- Vertical Forces on Rear Tyres (Fr) =74.129 kgs (163.427 lbs)

➢ A 2-D sketch in the CAD software (chassis design and track width from which it will determine the length of the control arms).

➢ Using the same 2-D sketch to find the Instantaneous Centre and Roll Centre (front and rear).

➢ The location for mounting points on the chassis for each joint at the arms.

➢ Whether the suspension geometry satisfies the requirement using Optimum Kinematics or Lotus Shark.

➢ Calculate the spring stiffness and damping coefficient.

➢ Designing of different suspension components.

➢ Performing thermal and stress analysis on different suspension parts.

➢ Make revisions if required.

➢ Assembly of the suspension system.

➢ Test, tune, and optimize the geometry based on handling with the help of test driver.

MATERIAL SELECTION:-

➢ **MS AISI 1018**

As per our research and survey we have come to the conclusion to use AISI 1018 for Suspension Arms, Pushrod, and Uprights. The composition includes Carbon (0.14% - 0.20%), Iron (98.81% to 99.26%), Manganese (0.6% to 0.9%), Phosphorus (less than or equal to 0.04%), Sulfur (less than or equal to 0.05%). These possess the properties which is better than the competition i.e. max strength is 270 MPa compared to S235 at max 160 MPa. It does have 9% more Shear strength, 8% more compressive strength as compared to S235.

The possessed properties are

1) Ultimate tensile strength = 350 MPa

2) Yield Strength = 276 MPa

3) Elongation = 17%

4) Bulk Modulus = 140 GPa

5) Shear Modulus = 26 GPa

6) Poisson's Ratio = 0.33

7) Machinability = 50%

The price is Rs 65 /kg vs. 60/kg for Steel S235 but for the properties it possesses the extra cost is worth it.

Aluminum Alloy 7075 T6

As per our research and survey we have come to the conclusion to use Aluminum Alloy 7075 for Bell-Crank. Chemical Composition of this Alloy includes:- Silicon(0.4%), Copper(2%), Magnesium(2.9%), Manganese (0.3%), Iron(0.5%) , Chromium(0.28%), Zinc(6.1%), Titanium(0.2%) and remaining is Aluminum. The price of the alloy is 600/kg.

Properties of the alloy includes:-

1) Density = 2.8 gm/cc

2) Melting Point = 483°C

3) Tensile Strength = 220 MPa

4) Fatigue Strength = 160 MPa

5) Hardness = 60 Hv

The tensile strength of 7075-T6 is nearly double to that of 6061-T6 having 276 MPa.

The shear strength of 7075-T6 is roughly 1.5 times to that of 6061-T6 having 207 MPa

Steel S335

- As per our research and survey we have come to the conclusion to use Steel S335 for Rod Ends and Arm Ends.

The maximum Carbon and manganese concentrations are higher for S355 thus making it strong as well as flexible enough to withstand the repeated load that will act on it during the working of the system.

The concentration of C is 0.20 – 0.24% and of Mn is 1.6%, respectively for S335.

Bearings

For Bearing we have considered Fluro 16 Bearings as this is a standard bearing and is widely used in FSAE cars.

5. CONCLUSION

The purpose of this project is not only to design and manufacture the suspension system for the car, but also to provide an in-depth study in the process takes to arrive at the final design. With the design being rigorously thought-about beforehand, the producing method being controlled closely, with several design options are prove effective within the performance demand of the vehicle. The FEA analysis indicates that the suspension system is able to perform safely in real track condition as per performance requirement.

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