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Modelling And Analysis Of Suspension System Under Mechanical Loads

A Comprehensive Analysis Under Mechanical Loads

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Abstract : The objective of presented work is to layout the optimum methodologies to design an efficient Suspension system of a formula student vehicle. This report is final output of the suspension design and analysis presentation at Formula Bharat Competition 2020. Entire work was performed under Formula Bharat rulebook restrictions and guidelines for an efficient vehicle buildup accompanying optimum speed considering excellent ride comfort. The paper enlists various methodologies adopted for design and analysis of suspension system which includes control arms, pushrod, bell crank, damper springs and knuckle. LOTUS software was used for static and dynamic analysis of suspension assembly considering various geometrical attributes such as Roll center, Wheel travel and various wheel alignment angles such as Camber, caster and toe angles. The 3D modeling of the system assembly was performed on SolidWorks whereas the analysis was carried on both Autodesk Fusion 360 & ANSYS workbench.

***IndexTerms* - Double Wishbone Pushrod System, Bell Crank, Suspension Damper & Spring, LOTUS software, ANSYS simulation software, Knuckle & Hub, CATIA.**

1. INTRODUCTION

The purpose of the car’s suspension is to keep all four wheels in optimal contact with the ground under any and all conditions. A well-designed suspension must handle bumps and uneven surfaces as well as dynamic cornering, braking, and acceleration. The FSAE car is a racecar purpose built for a prepared track, so performance and handling will be prioritized over smoothness and suspension travel. It is generally a system of shocks (dampers), springs, uprights and arms that altogether keep a vehicle suspended above ground on its wheels. The major component involved in the system includes damper & springs, wishbones, knuckle/upright and wheels. A Double wishbone Pushrod actuated suspension design was primarily used because of the aerodynamic and adjustability advantages it gives. They consist of an inboard mounted spring a push rod and a bell crank assembly. The main requirement here is a structure that will absorb the energy and transfer it to the frame without disturbing the whole system. The study of the forces at work acting on a moving car is called vehicle dynamics, and the concepts required for designing suspension system are clearly encapsulated further.

2. DESIGN METHODOLOGY

For the competition we used pushrod suspension system due to its high structural strength and its ease of track tuning.
The main requirements for the suspension system are:

- ✓ It should have a minimum travel of 25 mm in both jounce and travel.
- ✓ The system must be responsive and also stable enough to give best performance in cornering and straight line.
- ✓ The system should be such that it should help maintain maximum tire contact patch for better friction.
- ✓ It must be structurally strong but also lightweight to maintain low unsprung mass.

Following above assumptions after multiple iterations over ANSYS software the various basic parameters were decided & discussed upon and finally confirmed at requisite values:-

1. WheelBase : 1727 mm

2. Front Track-width: 1300 mm

3. Rear Track-width: 1300 mm

4. Camber Angle : -1.50 in front and -10 in rear

5. Caster Angle: 60 (front) & -60 (rear)

6. Toe Angle: 0.30 in front and -0.30 in rear

7. Kingpin Inclination: 2.50 in front and 20 in rear

8. Total Mass of Vehicle(with driver):310 kg

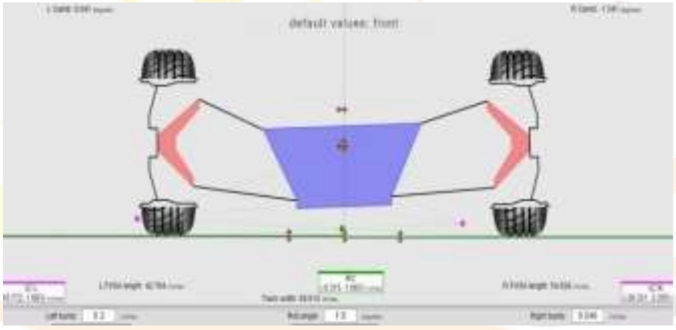
9. Sprung weight: 210 kg

10. 10.Weight distribution : 45:55 (front: rear)

2.1. BASIC GEOMETRICAL SETUP

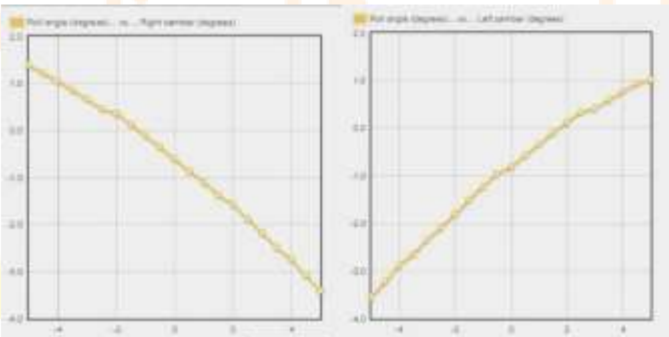
The process of assembly designing was initiated with at first geometrical parameter such as Roll Centre and Roll Height setup followed by proper Wheel alignment angles and plotting its graphical analysis.

The initial setup affixed with some parameters:



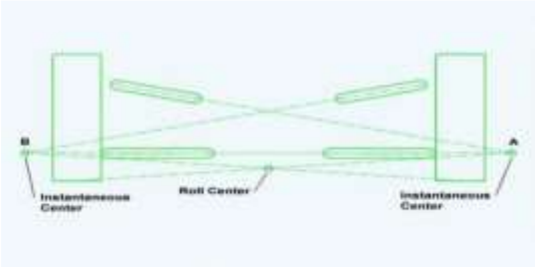
The Right Wheel Camber:
It was adjusted to approx. -1.50 as stated already before with requisite values of Roll Angle, Roll center so as to stabilize the camber value.

Some geometrical attributes related to camber procure certain plots as:-



Roll Center adjustments:
The roll centre positions of your front and rear suspension geometry are key features affecting the lateral load transfer rates of your front and rear axles. Their position and difference in height front to rear can be used to tune the roll stiffness distribution of your car in a similar way that you would adjust the stiffness of your front and rear roll bars to tune understeer and oversteer.

If the roll centre is located above the ground the lateral force generated by the tire generates a moment about the instant centre, which pushes the wheel down and lifts the sprung mass. This effect is called Jacking. If the roll centre is below the ground level the force will push the sprung mass down. The lateral force will, regarding the position of the roll centre, imply a vertical deflection. If the roll centre passes through the ground level when the car is rolling there will be a change in the movement direction of the sprung mass.

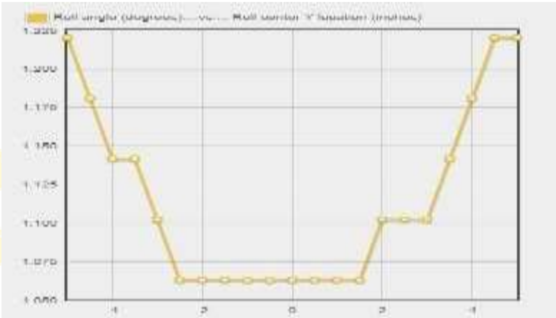


Geometrical setup to get Roll center

Decision

Roll centre Height of Front suspension was kept 22mm and of Rear Suspension as 58mm. Rear Roll Centre Height is kept more to keep our car aerodynamically stable at High speed also.

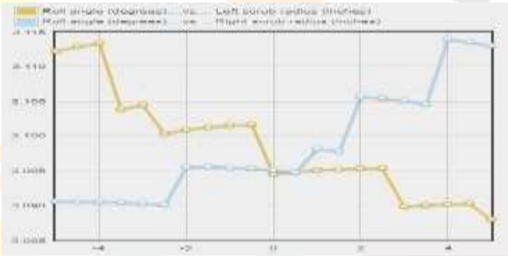
The graphical comparison with camber angles were plotted as :-



Kingpin Inclination

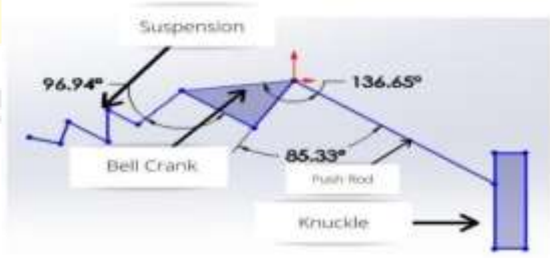
As stated above the KPI was setup to 2.50 in front and 20 in rear the requisite scrub radius was further calculated and plotted alongside Roll angle variations under dynamical aspect of vehicle.

The graph is observed for both bump and droop conditions which is on left and right side plot respectively.



2.2. SUSPENSION COMPONENTS DESIGN

The initial iteration of wheel alignment and geometrical setup ascertain certain suspension hard points both in chassis and knuckle for different parts accommodation in between such as control arms, bell crank, pushrod and coilover (dampers) in an aesthetic manner.



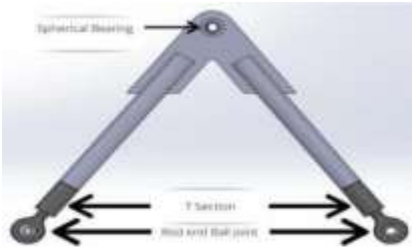
Geometrical setup of suspension parts

2.3. Material Selected for suspension components:

The material selected for suspension design components including A-arm and other mountings & platforms for the vehicle was AISI 4130 Mild Steel which embodies a good range of supportive features to be ideal for a Vehicle system.

Suspension Control Arms:

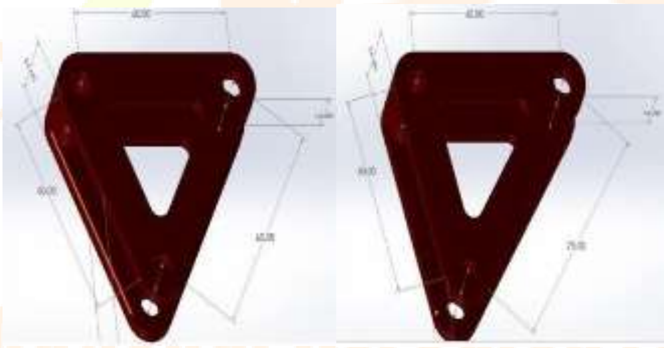
A-Arms or Control Arms design started with CAD geometry drawing using suspension compartments and considering track width, wheelbase and other similar parameters. Selection of material for A-Arm was done as per Material availability and Machining cost. The CAD model of control arms with its other sections is depicted as:-



Lower and Upper Control Arms

Bell Crank

A bell crank sometimes depicted as rocker armaids in transferring bump and droop motion during vehicletranslation from wheels via pushrod to suspension dampersin order to ascertain healthy ride comfort. To overcome the unequal load distribution which occurs with the reactive balance beam suspension when either driving or braking, anon-reactive bell crank lever and rod linkage has been developed which automatically feeds similar directional reaction forces to both axle rear spring end supports. Afterproper dimensioning and load calculations the CAD model of bell crank was setup.



Knuckle & Hub

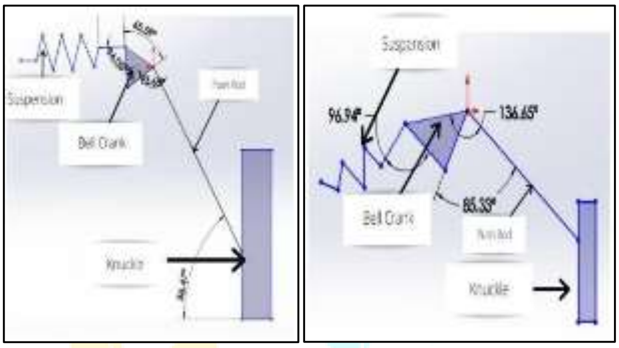
Knuckle is the non-rotating part in the wheel assembly. The stub axle is welded on the knuckle. Anychange in the shape of knuckle can lead to the change in thesuspension geometry. The rear hubs were designed in parallel with the front hubs, since they are the main interface between the suspension and the tire. In order to simplify manufacturing, the rear hubs were created identical to the front hubs, with the exception of the wheel bearing preloadhardware and the addition of a torque transmission method. However, the hub is completely encased in this region by the wheel bearing which is Angular contact roller bearing, so no yielding should occur.

Front and Rear Knuckle

3. Analysis

The analysis was performed for various suspension assemblies like control arms, bell crank, suspension springafter proper load applications in order to ascertain stress and displacement factor of parts during action of load dynamically during vehicle in motion.

3.1. Geometry Considered



Front and rear geometrical figures

3.2. Analysis of Control Arm

For control arms analysis we start with load calculations in front and rear suspension's A-arms both upper and lower during knuckle movement encountering cornering or braking and the same with the chassis movement.

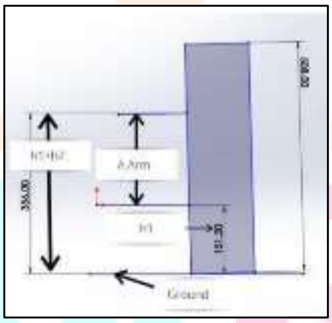
Load Calculations:

Max cornering force= 3720NTotal lateral weight transfer

= (cornering force) x (cg height) / (trackwidth)

= (3720 x 288)/1300 = 824.12N

The calculation was performed based on A-arm position inreference to knuckle mounted to the wheel hub.

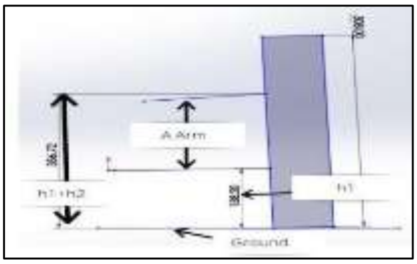


Vertical wheel load = 1305.6N

On applying dynamic multiplication factor$F_{vertical}$ = 1.3x1305.6 = 1697.28N

$F_{lateral}$ = 1.2x 1697.28N = 2036.7N

Force on upper A-arm = (Flat xh1)/h2 = 1503.62N Force on lower A-arm = (Flat xh1+ h2)/h2 = 3542.3N



Outer vertical wheel load = 1068.35

On applying dynamic multiplication factor Fvertical = 1.3x1068.35 = 1388.8N

Flat = 1.2x1388.8 = 1666.67N

Force on upper A-arm = (Flat xh1)/h2 = 1328.3N Force on lower A-arm = (Flat xh1+ h2)/h2 = 2994.8N

3. Suspension spring simulation

Load Calculations:

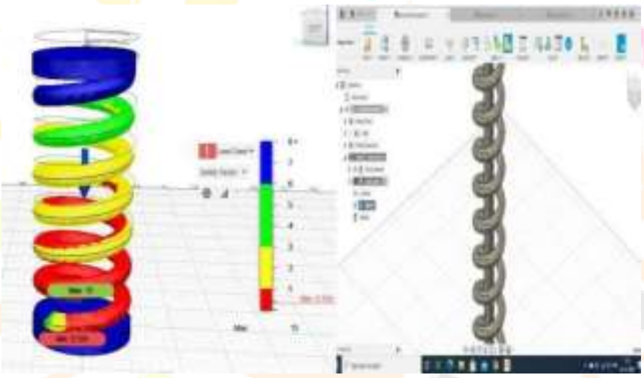
The load will be transmitted parallely without any aberration from pushrod to suspension spring via bell crankso as to compress it towards chassis.

So,

$F_{front\ suspension}$=2242.8N$F_{rear\ suspension}$= 3019.2 N

Fixing the other end as it is to be mounted on chassis and applying loads on the another end as calculated above , we get the output over Fusion 360 as:

Output:



4. ANALYSIS OF COMPLETE SETUP

The complete setup of suspension assembly ranging from wheel & knuckles to control arms arranged altogether so as to ascertain Pitch and Roll Analysis for an efficient suspension system. The different values obtained as calculated above were input and the results of setup were iterated for both static and dynamic condition of Vehicle.

TYPE 14 Double Wishbone, Push Rod to damper

INCREMENTAL GEOMETRY VALUES

BUMP TRAVEL (mm)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPIN ANGLE (deg)	DAMPER RATIO [-]	SPRING RATIO [-]
-30.00	-1.2765	-0.6583	5.9925	2.4980	1.735	1.735
-20.00	-1.2652	-0.5933	5.9924	2.4798	1.579	1.579
-10.00	-1.2821	-0.5550	5.9925	2.4927	1.444	1.444
0.00	-1.3265	-0.5414	5.9927	2.5357	1.321	1.321
10.00	-1.3981	-0.5507	5.9930	2.6083	1.204	1.204
20.00	-1.4970	-0.5814	5.9935	2.7104	1.086	1.086
30.00	-1.6236	-0.6325	5.9942	2.8423	0.956	0.956

 REAR SUSPENSION - BUMP TRAVEL
RHS WHEEL (+ve Y)

TYPE 14 Double Wishbone, Push Rod to damper

INCREMENTAL GEOMETRY VALUES

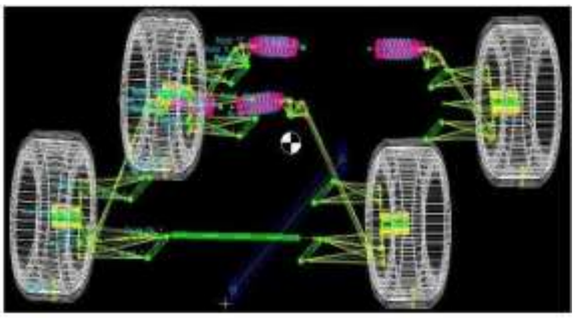
BUMP TRAVEL (mm)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPIN ANGLE (deg)	DAMPER RATIO [-]	SPRING RATIO [-]
-30.00	-0.3223	0.3776	-5.9964	1.2758	1.281	1.281
-20.00	-0.5602	0.3492	-5.9970	1.5107	1.276	1.276
-10.00	-0.8151	0.3245	-5.9977	1.7630	1.272	1.272
0.00	-1.0882	0.3034	-5.9987	2.0339	1.271	1.271
10.00	-1.3810	0.2865	-5.9998	2.3249	1.278	1.278
20.00	-1.6950	0.2739	-6.0012	2.6376	1.298	1.298
30.00	-2.0324	0.2664	-6.0029	2.9742	1.342	1.342

The bump and roll simulation output was confirmed after bump force calculations on wheel

At the time of a bump in the surface a force will act on the portion of the bearing which is inside the knuckle. This is because the hub is bolted directly to the wheel. This force isobtained from the wheel rate. For design purpose the wheel rate is kept as 45N/mm².

Also it is considered that there will be no bump more than30mm as the track is extremely flat.

Bump Force = Wheel rate × Travel due to bump = 45× 30
=1350 N



Bump simulation

5. CONCLUSIONS

This paper sums up the basic design and analytical concepts of the suspension system used in student formula car. Afterdesigning wishbones, knuckle and spring 3D model built with the help of CATIA, SOLIDWORKS and analysis done on ANSYS workbench. Integral assemblies were simulated on LOTUS software. Results obtained by simulation match withdesigned parameters. And after analyzing various suspension components, the paper lays down a methodologyfor analysis of different components. The FSAE guidelines have been thoroughly followed while working on this paper.Besides, it is to be noted that "Iteration is the key to perfection".

6. ACKNOWLEDGMENT

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