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Design and Development of Semi Trailing Arm Suspension System for an Off-Road Vehicle

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***Abstract*: ATV is a basically an off-road vehicle with capability to withstand harsh road conditions. Stability, control, performance, and comfort these are the basic requirements for an ATV. Suspension system is one of the important systems which is responsible for fulfillment of basic requirements. This paper is based on design and development of semi-trailing arm suspension for ATV. The report describes the methodology followed to design a system and analysis of suspension components undergoing major forces during dynamic conditions. The main objective is to design and develop a suspension system which improves overall performance and handling properties of ATV.**

***Keywords*: Half shaft geometry, Independent suspension, SAE BAJA, Semi trailing arm, Structural analysis, Suspension geometry.**

1. Introduction

Semi-trailing arm suspension is multilink independent suspension system which provides better ride control and stability to vehicle. The design of suspension system should be able to sustain at worst condition. The main target is to design the suspension system which can provide more comfort, light weight, better handling, better shock absorbing capacity, vehicle stability, less complexibility. By taking all these considerations we design suspension system which gives us better performance and also the cost efficient.

This report is based on step by step design methodology followed by Team Galactus racing for BAJA SAE India competition. Baja sae India is a national level competition for especially for engineering students. ATV is design and manufactured for competition purpose which demands a vehicle which is able to survive worst road conditions. Suspension system plays major role in control and stability of vehicle. Semi-trailing arm as rear suspension has many advantages over other suspension types.

Objectives of suspension system:

1. To minimize shocks and vibrations occurring due to road irregularities and provide comfort to driver.
2. To provide cornering stability to vehicle.
3. To maintain ground clearance.
4. To provide stability during dynamic conditions.
5. To resist pitch, roll and yaw movement of vehicle.

2. Advantages of Semi-Trailing Arm Suspension

1. As semi-trailing arm suspension is a 3-link independent suspension it provides better ride quality and handling.
2. In semi-trailing arm suspension during the suspension movement the camber angle changes, as a result the tyres remain perpendicular to the ground during body roll.
3. Lower cost, less complexity and more compactness.
4. It provides better lateral load handling capacity.
5. Better antisquat properties.

3. Design of Semi-Trailing Arm Suspension

A. Deciding vehicle dimension (Wheel base and wheel track)

1) Design Methodology

First step in suspension design is to decide wheel base and wheel track. As per the rule mentioned in BAJA SAE rulebook maximum dimension is within limit of 64in width by 108in length. So, wheel base kept minimum to minimize turning radius and track width also kept moderate according to wheel base to maintain stability during maneuver. Also we did load transfer iteration for different wheel base and wheel track and CG height combination and for balanced load transfer we come up with following values:

Wheelbase =56in and Wheel track=52 in

It will results in minimum load transfer and also leads to better stability.

B. Suspension geometry

1) Semi-trailing arm suspension geometry

After deciding vehicle dimensions next important part is suspension geometry. Suspension geometry is one which is directly affect on performance of system. Therefore, it is very important to design geometry with all considerations achieve system objectives. For semi trailing arm geometry we take some considerations like ground clearance, wheel dimensions, and upright dimensions. According to this we draw geometry in catia software. The angle for semi-trailing arm is adjusted according to roll centre height. For rear we are using Fox float Evol R.

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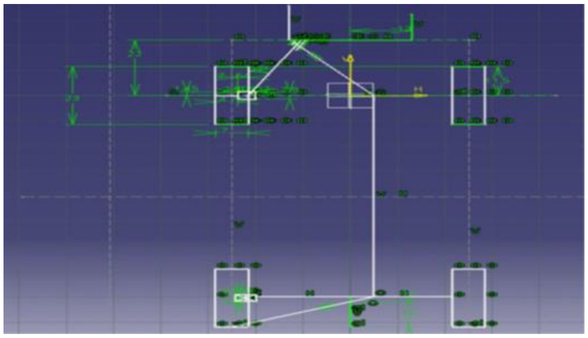

Fig. 1. Semi-trailing arm suspension geometry

2) Half shaft geometry

When the driving wheels of a vehicle have independent suspension, which means that each wheel can move up and down independently of the other, then you will find that the transmission will be hard mounted to the frame, and "half-shaft" axles will connect between the transmission and the driving wheel. This axle has CV (constant velocity) joints on both ends. CV joints allows some degree of freedom to the axle so as per independent motion of suspension axle can be adjust without loss in power/torque.

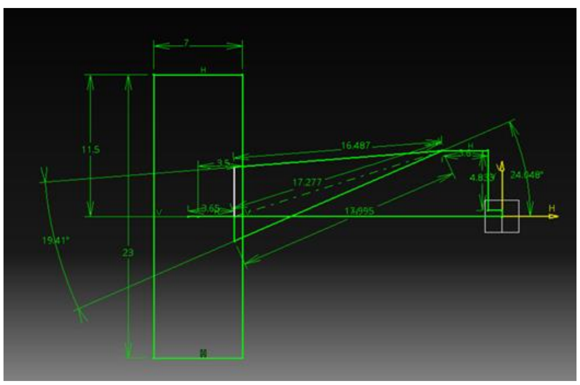

Fig. 2. Half shaft geometry

Table 1
Suspension parameters

Wheelbase	56in
Wheel track	52in
Ride height	12in
CG height	20.12in
wheel travel rear bump	4 in
Wheel travel rear droop	2 in
Roll center height rear	8 in

According to the suspension geometry half shaft geometry is designed to check the working range of CV joints. CV joints has 2 inch of lateral plunging moment also it can vary its own length by ±1 inch. From the geometry length and the inclination angle of half shaft is decided. Inclination of angle from CV joints can be works till 35°, after that there may be problem with insufficient plunging moment results in loss in integrity of the CV joints.

Maintenance of these CV joints are plays important role for better life. CV joint boots are used to cover protect the joint, which is nothing but rubber sleeves around the CV joints. The boots keep grease in debris out.

In geometry we get the travel of the half shaft along with wheel travel. The plunging moment of the half shaft is 1.5inch and angle of inclination is 24°.

C. Design of semi-trailing arm

Design of semi-trailing arm and upright is done as per length and other required dimensions obtained from geometry. Modeling of semi-trailing arm and upright is done in solidworks.

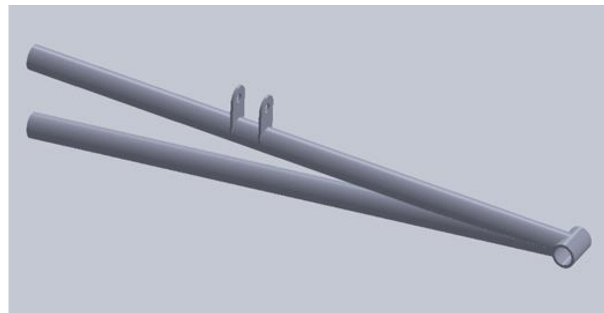

Fig. 3. Semi-trailing arm

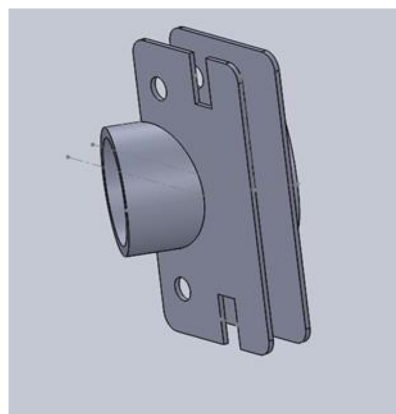

Fig. 4. Upright

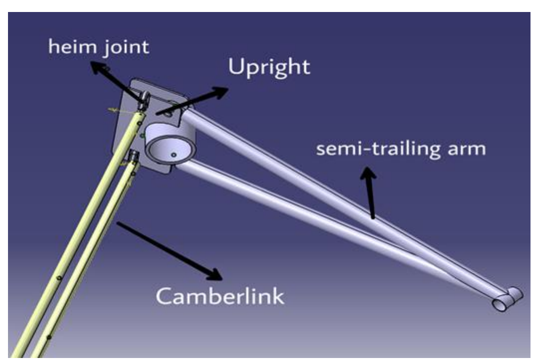

Fig. 5. Assembly of trailing arm and camber link

- *Material selection:*

Material selection is important for design of any component. By comparing different materials, we select AISI 4130 material for semi-trailing arm and Al7075 t-6 for upright and hub. These materials have significantly higher ultimate tensile strength and yield strength as compared to other materials.

Table 2
Material properties

Properties	AISI 4130	Al7075 t-6
Density	7850 kg/m^3	2810 kg/m^3
Yield strength	435MPa	503MPa
Ultimate tensile strength	670MPa	572MPa

1) Free body diagram of semi-trailing arm

A free body diagram is very helpful method to calculate the number of forces coming on semi-trailing arm. It is essential to calculate forces to determine sustainability.

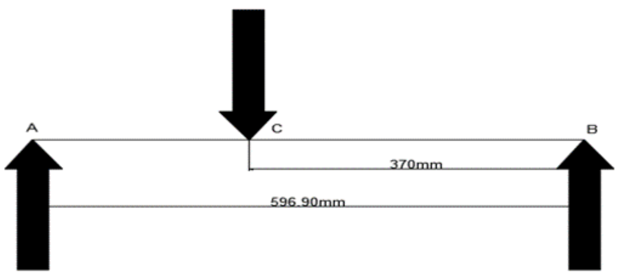

Fig. 6. Free body diagram

In the above free body diagram:
Consider,
A- Pivot point of semi-trailing arm on chassis
B- Pivot point of semi-trailing arm on upright.
C- Point of attachment of damper.

2) Force Calculation

As per the diagram, we calculate forces:

Weight of the vehicle: 230kg (with driver).
Weight on rear portion: 60% of total weight =138kg
Weight on one wheel: 69kg

Point of attachment of strut = 370mm
…. (From suspension geometry)

Reaction force acting from the ground on the wheel 3G
= (Mass per wheel * 9.81*3) N
= (69kg * 9.81*3) N
= 2030.67N
By taking moment about hinge point:
$=2030.67 \times 596.90 = Fc \times 370$
F_C = 3275.96N.

Force at A=
Summation of all vertical forces is zero $\sum Fy = 0$
F_A= 3275.96 – 2030.67 = 1245.29N.

Bending moment on trailing arm:

At point B,
M_B=0

At point C,
$M_c = 2030.67 \times 370 = 751.347 KNmm.$

At point A,
$M_A = (2030.67 \times 596.90) - (3275.96 \times 226.9)$
$= 468.791 KNmm.$
F_A= 1715.99 – 1277.262 = 438.728N

3) Force calculation and analysis of upright

As per the road condition forces acting on upright are as follows:
Load calculations:

Weight of the vehicle: 230kg (with driver).
Weight on front portion: 40% of total weight =92kg
Weight on one wheel: 46kg
Loading type:
1. Bump condition= 4G:
$=4 \times 9.81 \times weight\ on\ one\ wheel.$
$=4 \times 9.81 \times 69 = 2707.56N$

2. Cornering and acceleration= 4G:
$=4 \times 9.81 \times weight\ on\ one\ wheel.$
$=4 \times 9.81 \times 69 = 2707.56N$

- *Ansys results:*

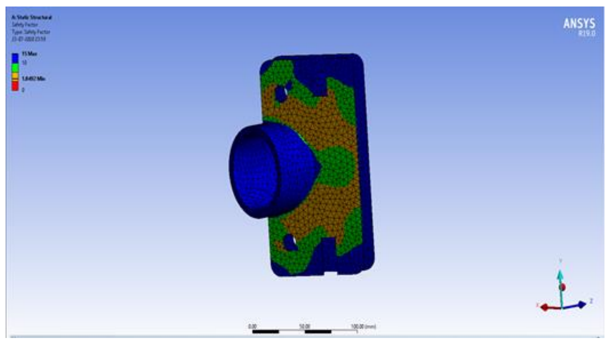

Fig. 7. Factor of safety

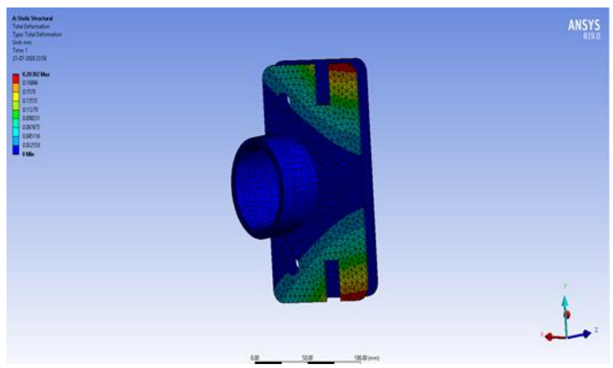

Fig. 8. Total Deformation

Table 3
Ansys results

Parameter	Upright
Factor of safety	1.84
Max. deformation(mm)	0.2030
Principle stress (MPa)	51.909

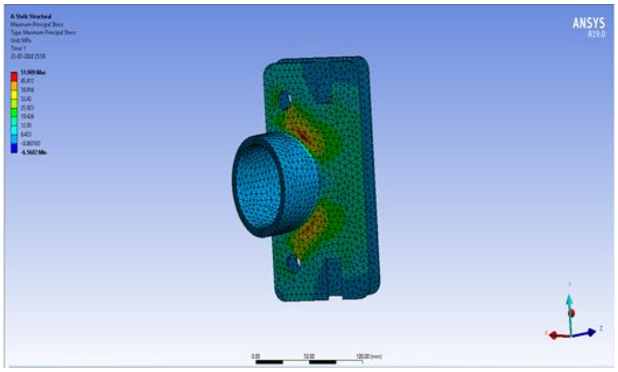

Fig. 9. Principle stress

4) Design and analysis of hub

The following Forces are acting on the Hub.

- *Torque on the Wheel Petal:*

In order to sustain this braking effect the wheel must also provide and equal and opposite torque. Therefore, the magnitude of torque is same but the direction is opposite. Therefore, Force on one hole = 1955.65 N

- *Force due to Side Impact:*

We have considered that the force to be applied due to side impact is 2G = 2 × g × vehicle mass.

Impact force = 2 × 9.81 × 230 = 4512.6 N

Impact force on 1 petal = 4512.6/4 = 1128.15N.

Force due to bump: 4G

$=4 \times 9.81 \times 46 = 1805.04N$

- *Analysis of hub:*

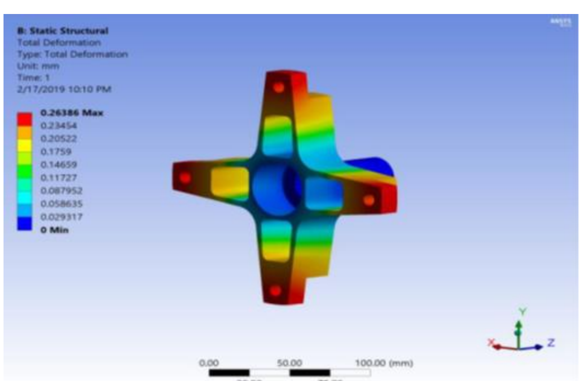

Fig. 10. Analysis of Hub

Table 4
Ansys results

Parameter	Hub
Factor of safety	1.56
Max. deformation(mm)	0.2638

4. Damper Selection

A. Damper: Fox float evol-r

Advantages:

In fox float Evol-r load optimizing air technology is used instead of spring it allows us to change the stiffness and to change ride height according to our design. Due to this, we can easily achieve CG height. It is made from Al6061-T6 material which makes it light weighted.it gives us variable stiffness which we can achieve by simply adjusting the pressure in the main chamber and evol chamber. Some main advantages of fox are following:

1. Lightweight.
2. Better damping capability than spring.
3. Better shock-absorbing capacity.
4. Adjustable stiffness.

Table 5
Damper Parameters

Wheel travel	Rear: 6in
suspension travel	5.3in
Motion ratio	Rear: 0.8
Spring rate (N-mm)	Rear: 19.86
Natural frequency (Hz)	Rear: 2.64
Ride rate (N-mm)	Rear: 18.40

5. Conclusion

When undertaking design of any vehicle; There are several factors to be considered that are common to all engineering vehicles. A vehicle must have proper scope with clearly defined goal. With such an approach, engineers can come up with the best possible product for the society.

The chosen design is the safest and the most reliable car for any long terrain. All the parameters like safety, cost, reliability, performance, durability, standard dimensions and material were also taken in consideration on the same time. Catia V5, Ansys, solid works were used to get more clear and accurate output of designed parameters to meet high accuracy and to reduce any type of any unlike situation.

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