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Design and Development of Front Suspension System for an Off-Road Vehicle

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***Abstract*: An off-road vehicle is a four wheeler car specially design and manufactured for all types of terrain. It is basically single driver car, capable to sustain in harsh road conditions which is designed for a competitive purpose. This paper is based on the design and development of a suspension system for an off-road vehicle which is designed and manufactured for an SAE BAJA INDIA competition. An off-road vehicle requires stability, better handling properties and good level performance. So the aim is to develop a suspension system which will give an output of good Performance and complete endurance for the vehicle. While designing suspension system one should consider all the Factors and parameters which are affecting on performance of a vehicle. This Paper includes all those parameters and also the methodology which is necessary while designing and developing a suspension system. Suspension system plays vital role of eliminating vibrations, providing stability to ATV and comfort to driver. The design of suspension System is optimized in such a way that it will results in a better maneuverability and ride comfort. This report consists of design considerations, design Requirements for system and step by step methodology to design a suspension system of ATV.**

***Keywords*: ATV, Double wishbone, Independent suspension, Optimization, SAE BAJA, Suspension geometry, Structural analysis.**

1. Introduction

BAJA SAE India is an intercollegiate design competition that provides a platform for engineering students to design and build an ATV. This report is about the design and analysis of the suspension system of ATV designed by Team Galactus racing.

For any vehicle better handling is necessary. Providing a high level of comfort is the sole responsibility of the suspension system. Spring, damper, suspension linkages together form a suspension system. Shock absorber plays an important role in eliminating shocks and providing comfort. It also helps to maintain ground clearance. Suspension linkages are provided connection of wheels to the body of the vehicle.

While designing any vehicle or system we have to keep some performance targets to achieve. Control, stability, and ride comfort should be the main targets to achieve for the suspension system. Along with this, we tried to reduce the weight of components to make vehicle lightweight which will help to increase overall vehicle performance. Therefore, it is important to consider each factor that will be going to affect performance. There are several factors or parameters of other systems that are affecting suspension design. Therefore, it is important to consider all those factors while designing. Design of suspension includes camber, caster, toe, roll axis, calculations for damper selection all these factors play an important role in the stability and performance of vehicles.

The basic procedure for the design of the system is as follows:

1. Deciding wheelbase and wheel track by considering weight transfer criteria.
2. Drawing of suspension geometry in CATIA.
3. The calculation for forces acting on suspension components.
4. Calculations for damper selection.
5. Analysis of suspension component in Ansys.
6. Simulation of the system.

The selection of material is also an important part of the design. It is very essential to select a suitable material which has good strength as well as low density. This report includes methodology followed to design of front suspension of an ATV.

2. Objectives

1. To support the vehicle in a static condition with desired ride height.
2. To maintain contact between tire and road.
3. To provide comfort to the driver.
4. To maintain vehicle stability and resist roll of chassis.
5. To absorb the shocks and dampen out the vertical forces coming on the vehicle.
6. Better handling of the vehicle during cornering, braking, and acceleration with desired suspension travel.

3. Design of Front Suspension

A. Selection of appropriate type of suspension

The selection of the type of front suspension will decide the further design procedure.

1) Double wishbone suspension

1. In SAE Baja the main requirements are the abilities to withstand harsh road conditions and the off-roading capabilities. This is possible in double wishbone

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suspension because of precise control over camber change. It provides designers more freedom to set camber and kingpin control on his own will as compared to other types of suspensions.

2. Plus, another advantage of double wishbone is to effectively distribute bump reactions to make the ride smoother.
3. Provide better handling and cornering properties.
4. Anti-dive properties can be easily set by making a simple Side view geometry.
5. The double-wishbone suspension system is much more rigid and stable than other suspension systems, thus you would realize that your steering and wheel alignments are constant even when undergoing high amounts of stress.

B. Deciding wheel base and wheel track

1) Design methodology

Wheelbase and wheel track is decided based on two criteria,

1. As per the rule mentioned in the BAJA SAE rulebook. (Maximum dimension is within the limit of 64in width by 108in length.)
2. Minimum Static and dynamic load transfer.

So, as per above-mentioned criteria, we did iterations for load transfer and come up with value,

Wheelbase =56in and

Wheel track=52 in

Which results in minimum load transfer and leads to better stability.

As our load distribution is 60:40 load at the rear is 60% of total weight i.e.128.4 kg and at the front, it is 40% of total weight i.e.85.6 kg.

Achieved values of load transfer for the above combination of wheelbase and wheel track are shown in the graph.

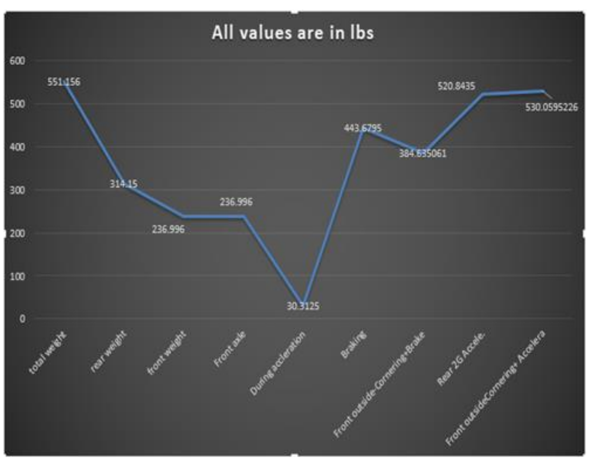

Fig. 1. Weight transfer variation

2) Load transfer calculations formulae

Centre of gravity height = CG_h

Initial distance from rear = CG_{xi}

Wheel base = WB_i

Weight of the car = M

Weight on front axle (F_{fi}):

$$F_{fi} = \left(\frac{CG_{xi}}{WB_i}\right) \times M \times \left(\frac{1ft}{12in}\right).$$

Percentage weight on front axle: $\frac{F_{fi}}{M}$

Weight on front axle during 2G acceleration (F_{fa}):

$$F_{fa} = \frac{M \times (g.CG_x + 2.g.CG_h)}{WB.g}$$

Weight transfer under 2G braking (F_{fb}):

$$F_{fb} = \frac{M \times (g.CG_x - 2.g.CG_h)}{WB.g}$$

Finding minimum track width for Max 2G force with inside tire load =0 lbs.

Summing the moments about (inside) tire:

$$TW = \frac{M \times CG_h \times 2g}{\left(\frac{-M.g}{2}\right) + M.g}$$

To find the force on the front outside tire, during both cornering and braking (F_{fo}):

$$F_{fo} = \frac{F_{fb} \times (g.CG_x + 2.g.CG_h)}{TW.g}$$

Force transferred to rear due to 2G acceleration (F_{ro}):

$$F_{ro} = \frac{F_{ra} \times (g.(WB - CG_x) + 2.g.CG_h)}{TW.g}$$

As soon as we decide our vehicle dimensions then the next important part is to decide other suspension parameters.

- Camber: We kept a slightly negative camber angle which will provide maximum contact between tire and road surface, better cornering stability, maneuverability, and also it didn't affect straight-line stability. The negative camber produces a camber thrust which will help to achieve better control and stability.
- Kingpin Inclination: kingpin inclination has an important effect on steering. We kept it as 8 degrees. It will result in a minimum scrub radius which improves steering properties and also and have better cornering properties.
- Toe angle: we kept zero toe, which is when distance between wheels ahead of centerline is similar to distance between the wheels behind centerline. It will provide moderate cornering and straight-line stability.

C. Suspension geometry

1) Double wishbone suspension geometry

Suspension geometry is one of the very important and crucial parts while designing a system. Here we need to consider each factor that affects geometry. Geometry decides the stability of your vehicle for example we should keep roll moment as minimum as possible because it will lead to rolling of vehicle. And rolling moment depends on the distance between C.G. and roll center. As we see here all factors are interdependent therefore we should design geometry by considering all affecting factors.

We design a suspension system for maximum suspension travel for better shock absorption and providing sufficient camber gain to provide grip during cornering.

As we are using Fox float Evol R it provides 5.3in travel. Roll center height and roll moment should be minimum to avoid rolling of the vehicle. We decide FVSA length for which minimum roll moment is to be achieved.

Formulae for deciding FVSA length:

$$\frac{deg.change\ of\ camber}{bump\ lenght} = \tan^{-1}\left(\frac{1}{FVSA}\right).$$

By using the above formula, we did some iterations for different bump lengths and degree of camber change.

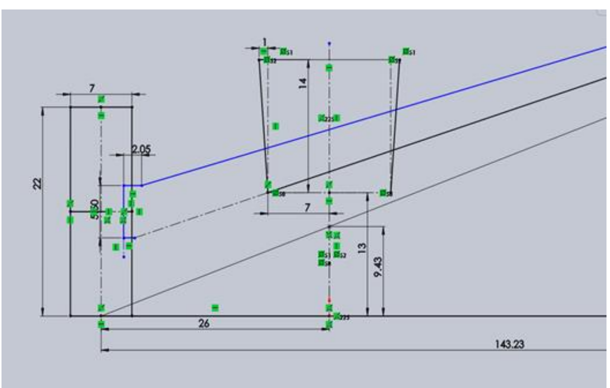

Fig. 2. Front suspension geometry

Table 1
Suspension parameters

Wheelbase	56in
Wheel track	52in
Ride height	13in
CG height	21.12in
Camber angle	-1°
wheel travel front bump	5.5 in
Wheel travel front droop	2 in
Degree of camber change	3°
KPI	8°
Scrub radius	0.93in
FVSA length	143.23 in
Roll center height front	9.43in

2) Antidive geometry

During sudden braking weight will be transferred from rear to front this causes a vehicle to dive. Due to this pitching movement of the vehicle can be occurred. To avoid this anti-dive feature is added to the vehicle.

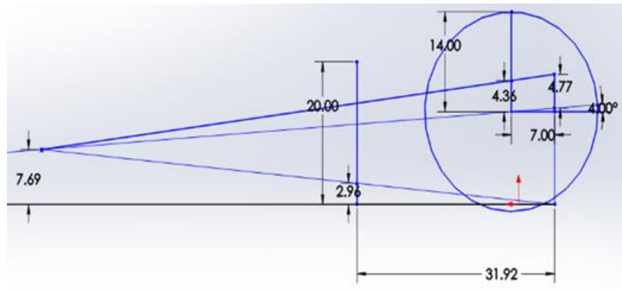

Fig. 3. Antidive geometry

Formula to calculate anti-dive percentage-

$$\%\ of\ antidive = \frac{m(\frac{a_x}{g})(\%front\ braking)(svsa\ height - svsa\ lenght)}{m(\frac{a_x}{g}) \times \frac{h}{l}}$$

3) Simulation of system

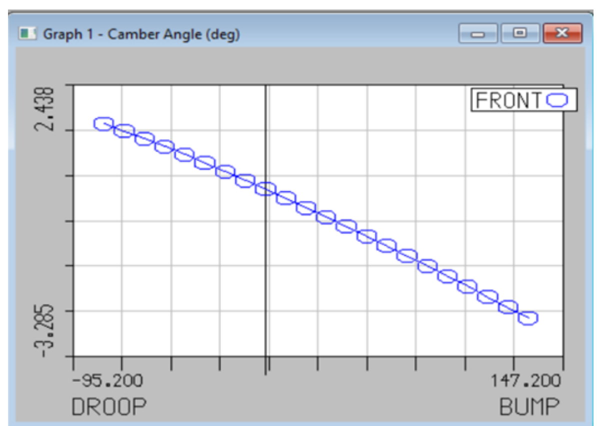

Fig. 4. Camber variation

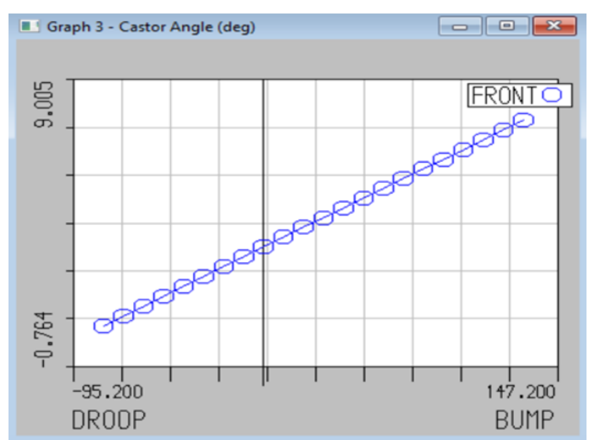

Fig. 5. Castor variation

Simulation of suspension is done in lotus shark software. It is a user-friendly software that provides various tools and geometry sets. We can directly insert hard points from 3-D modeling software. After inserting hard points software will give results in the form of a graph. So that we can verify results easily. As per the results, we can make changes in our geometry. One can easily verify the performance of a vehicle virtually in software. The figures 4, 5, 6 show the variation of values for a different condition.

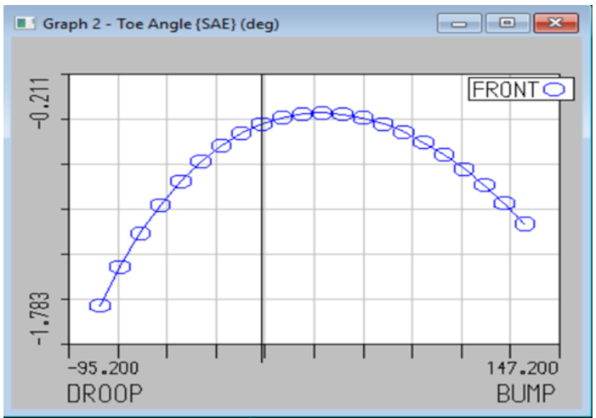

Fig. 6. Toe variation

D. Analysis of A-arm

1) Free body diagram of A-arm

Drawing of a free body diagram is necessary to calculate the number of forces coming due to sudden bumps. It is necessary to calculate forces in point of view of analysis. It will help to design a safer structure.

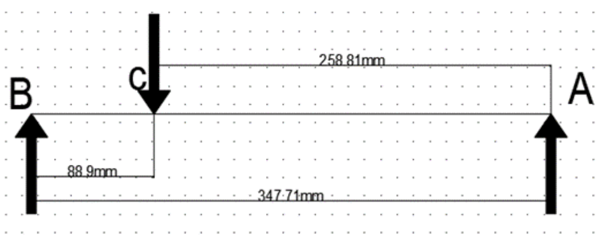

Fig. 7. Free body diagram

In the above free body diagram:

Consider,

A- Hard point of A-arm on chassis

B- Hard point of A-arm on knuckle

C- Point of attachment of damper.

From the geometry, we get the hard points and regarding to that, we make CAD model in software for A-Arm. And we analyzed it in Ansys software.

2) Force Calculation

As per the free body diagram, we calculate forces:

Weight of the vehicle: 217kg (with driver).

Weight on front portion: 40% of total weight =86.8kg

Weight on one wheel: 43.4kg

Point of attachment of strut = 88.9mm

…. (From suspension geometry)

Reaction force acting from the ground on the wheel 3G

= (Mass per wheel * 9.81*3) N

= (43.4kg * 9.81*3) N

= 1277.262N

By taking moment about hinge point:

$=1277.262 \times 347.71 = Fc \times 258.81$

F_C = 1715.99N.

Summation of all vertical forces is zero $\sum Fy = 0$

F_A= 1715.99 – 1277.262 = 438.728N

After forces calculation, it is essential to analyze the design. Analysis of A-arm design is done in Ansys software by applying all forces. Ansys is a finite element analysis software used to test strength, safety factor, and other related factors of structure. Before analysis material selection is important. We did a comparison for different available material by strength and density. And come up with the following results:

- *Material selection:*

As per material comparison, we select AISI 4130 material as it has significantly higher ultimate tensile strength and yield strength than AISI 1018. Both 4130 and 1018 have the same density, but 4130 gives more strength for same weight.

- *Ansys results:*

The dimensions for material are determined by the maximum bending stress generated in the suspension arm. The maximum bending moment is determined by shear force and bending moment diagram.

Бb = Mb*y/I

Where,

Бb - bending stress

Mb - Max bending moment

Y - Distance from center to outer fiber

I = Moment of Inertia of hollow pipe

The material selected for Suspension arm is AISI 4130 25.4(mm)*2(mm).

The factor of safety is 2.

Ansys provides results based on our force input. It determines the safety and strength of the structure in software and also gives precise and accurate results.

Table 3
Ansys results

Parameter	A-arm
Factor of safety	1.7404
Max. deformation(mm)	7.2065
Principle stress(MPa)	313.15
Max. equivalent stress(MPa)	264.31

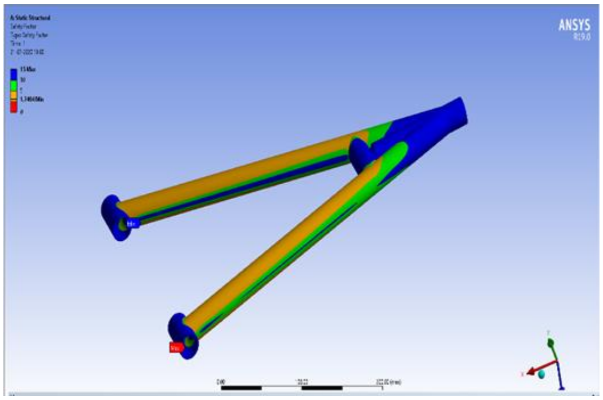

Fig. 8. Factor of safety

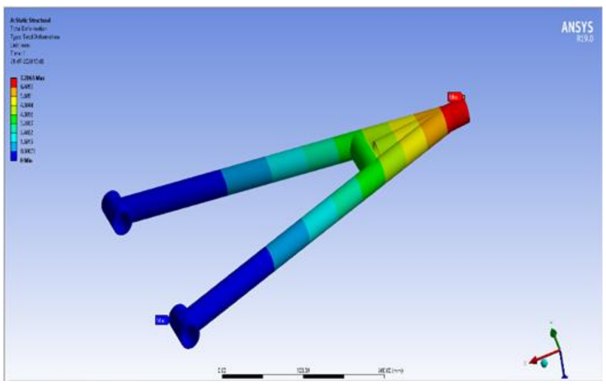

Fig. 9. Total Deformation

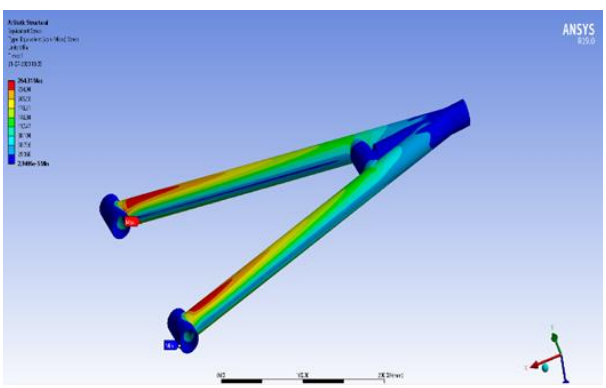

Fig. 10. Max. Equivalent stress

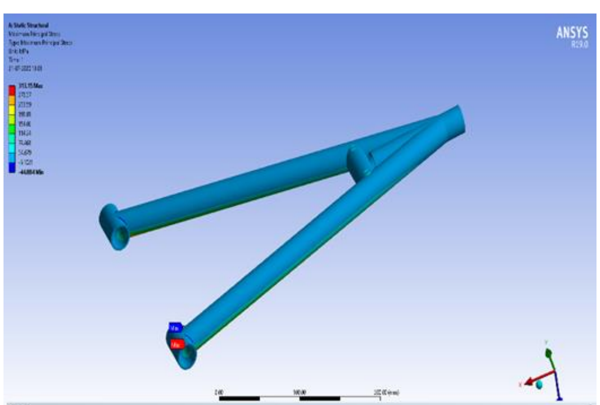

Fig. 11. Principle stress

4. Damper Calculations

1) Motion ratio

It is the ratio of wheel travel to spring travel. It is achieved in suspension geometry.

2) Spring rate: (ks):

It is force per unit displacement of spring.

S.R= spring force/ max. Travel of spring.

3) Wheel travel

Maximum vertical distance designed for a wheel to travel vertically during bump and droop. We decide it for maximum spring travel.

4) Suspension travel

The maximum length of the spring compresses or elongates when force is applied or removed.

5) Natural frequency

According to the flat ride concept, the natural frequency of rear should be greater than the front. It is the rate at which the body vibrates when it is not disturbed by an outside force.

$$F = \frac{1}{2\pi}\sqrt{\frac{K_s}{M}}$$

6) Ride rate

A vertical force applied per unit displacement of sprung mass with respect to ground.

Table 4
Damper Parameters

Wheel travel	Front: 7.5in
suspension travel	5.3in
Motion ratio	Front: 0.7
Spring rate (N-mm)	Front: 10.59
Natural frequency (Hz)	Front: 2.36
Ride rate (N-mm)	Front: 10.16

B. 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.

5. Conclusion

From the analysis and simulation of a system, we can conclude that:

1. The methodology followed to design the suspension system is appropriate and it helps to achieve stability and handling of a vehicle.
2. Simulation in lotus software shows the proper

working of a system in dynamic conditions.

3. According to Ansys results the component can withstand major forces and design is safe.
4. Selected material for A-Arm, AISI4130 gives high strength and helps to minimize weight.

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