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Design of Suspension System and its effect on different Sub-Systems in an ATV

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ABSTRACT

Suspension system is one of the important Subsystems in an ATV. It ensures both safety and comfort of the driver. The main aim of this paper is to design the suspension system of an ATV and explain the suspension parameters that have a significant impact on other subsystems such as the frame, braking, and steering. The study of relations between sub-systems is important because the effective functioning of the vehicle is dependent on the coordination between the two sub-systems. The design of suspension includes design methodology, design considerations, and design parameters of different components like the knuckle, hubs, control arms, and the result of iterations. Catia V5 and Solid Works are used to build the CAD model and Auto CAD is used for 2D projections furthermore Lotus Shark to acquire hard points of the suspension system.

Keywords: Suspension, Camber, Knuckle, castor, Control arms, Steering.

1. INTRODUCTION

The Suspension is one of the main sub-systems in an automobile. The suspension system is designed in such a way that when a vehicle is driven even on the uneven terrains it retains and acquires to its initial stage and stationary center of gravity. Shock Absorbers, wheel assembly , and the control arms that together constitute a suspension system connect the frame to the wheels and allow the relative motion between them.

The objectives of the suspension system are:

1. Reduces unsprung mass that in turn provides good ride and handling performance.
2. To make sure that the vehicle acknowledges well to control forces produced by tires during braking, cornering and accelerating.
3. To maintain maximum contact between the wheel, and the road.
4. Reduce unwanted roll of the frame.

1.1 Classification of the Suspension System

The Suspension system is broadly classified into dependent and independent suspension systems.
Dependent Suspension System: This type of suspension system connects the left and right wheels with a solid axle. This results in the working of both the wheels together.
Independent Suspension System: This type of suspension system has independent linkages to all the four wheels.

Advantages of Independent Suspension System over dependent Suspension System:

The bump and the rebound of a right wheel do not affect the other wheel; it ensures maximum contact between the wheels and the road.
The Independent suspension system provides more comfort in comparison to the dependent system.
In Independent Suspension System Mc Pherson Strut and Double Wishbone, suspension systems are majorly used.
Mc Pherson Strut: In this type of system, the shock absorber is directly mounted on the upper arm eliminating the upper control arm.

Double Wishbone suspension: In this type, two control arms, i.e. the upper control arm and the lower control arms are used. The shock mounting can be done on the upper control arm or lower control arm. The double wishbone suspension is chosen over the McPherson strut system because it provides sufficient camber gain during the cornering, which is important for the control, and the handling of the vehicle.
Because of the McPherson strut system's lengthy assembly, the ground clearance would be increased. Nevertheless, in the ATV's the ground clearance should be as low as possible to avoid rollover of the vehicle.

1.2 Material selection for different components

The chosen material for control arms is AISI 4130 because of the following reasons:

1) Good strength
2) Wear resistance
3) High strength to weight ratio

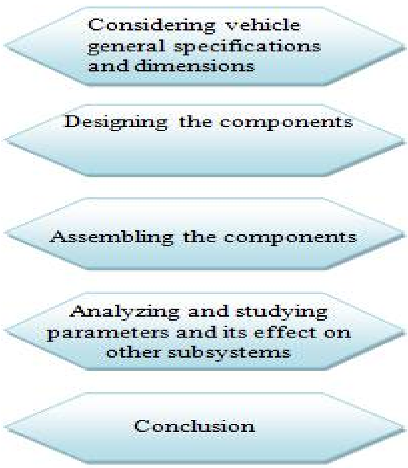
Mild steel is chosen for the knuckle and Al7075T6 for the hub. The properties of these three materials are:

Table 1: Mechanical Properties

S.no	Parameters	Mild steel	AISI 4130	Al7075T6	Units
1	Density	7.85	7.85	2.81	g/cc
2	Tensile strength, Ultimate	440	670	572	MPa
3	Tensile strength, yield	370	435	503	MPa
4	Modulus of elasticity	205	205	71.7	GPa
5	Poisson's Ratio	0.29	0.29	0.33	-

2. METHODOLOGY

Figure 1 shows the methodology of the study.



3. DESIGN OF INDIVIDUAL SUSPENSION COMPONENTS

Before designing the individual suspension components, we have to decide the overall vehicle details and dimensions.

Table 2: General considerations

S.NO	PARAMETERS	VALUE
1	Sprung mass	80kg
2	Unsprung mass	200kg
3	Track width	1350mm
4	Wheel base	1660mm
5	Wheel Dimensions	23in*8in

3.1 Knuckle

It is one of the main components of the suspension system. The role of the knuckle is to hold the tie rod, control arms, and the brake caliper together. Catia V5 is the software that has been used to design the knuckle.
Firstly, the size of the knuckle should ensure that there is a clearance between the ball joints that are mounted on the knuckle and the rim of the wheel. The OEM brake caliper should be decided before designing the brake caliper mount on the knuckle.

The various mountings on the knuckle are:

1. Lower control arm mount
2. Upper control arm mount
3. Steering arm mount
4. Brake caliper mount

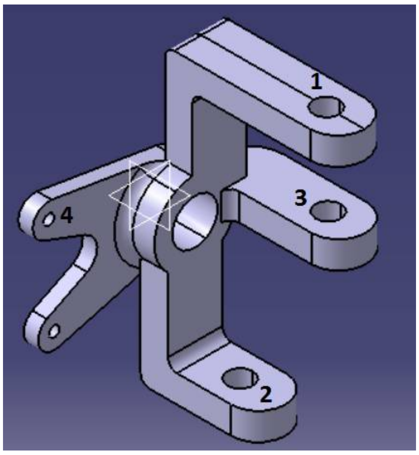


Figure 2: Knuckle

Table 3: Knuckle Parameters

Knuckle Parameters		
S.NO	**PROPERTIES**	**VALUE**
1	Castor angle	5^o
2	King pin inclination	12^o
3	Scrub radius	+35.5mm

4	Mechanical trial	25.48mm
5	Toe in	1^o
6	Camber Angle	-2^O

Based on simulation results of ATV for different values of knuckle parameters the following conclusions are drawn: The Positive castor angle enhances steering wheel returnability but also increases steering effort. The trials to build a knuckle with negative castor angle is not efficient because it may decrease the steering effort of the driver but creates wheel wandering problem thereby decreasing the stability while moving in a straight line. The optimum castor angle is chosen as 5 degrees based on the steering effort of the driver.

The distance between the center of the contact patch of the tyre and the king pin inclination intersection on the ground in front view is called a scrub radius. The distance between the tyre intersection with the ground and the castor angle intersection on the ground in the side view is called kinematic trail. The mechanical trail produces a moment, which increases the steering wheel returnability and the steering effort of the driver. The ideal scrub radius should be negative because the positive scrub radius produces a turning effect, but due to the constraints like wheel offset and the size of the knuckle, the scrub radius has been designed to a least possible positive value.

3.2 Control Arms

The length of Control arms is designed in an online suspension Analyzer. The dimensions of the arms are crucial because the camber change rate, scrub radius change, in course of the bump, rebound, and roll of the vehicle is dependent on arms and this can be analyzed with this software. We have chosen Double Wishbone Type, Damper to lower Wishbone for the front; H Frame lower and Single upper link for the rear.

The design of the Control arms is made in Solidworks. Firstly, we have to decide the tubular cross-section of the arms. The dimensions are drawn and the weldments are added to the drawing. The components of the suspension system are assembled in Solidworks to ensure there is no collision between any two components. The ATV is generally designed at static negative camber. The lengths of the arms are decided after going through a series of iterations. The upper control arms is designed a bit smaller because when the wheel goes through a bump or any corner, it takes the inward curve and compensates with the negative camber and maximum contact of tyre with ground takes place. After the arms have been designed, it is crosschecked that the camber is not positive throughout the wheel travel.
The motion ratio is decided by the point where the shock absorber is mounted on the control arm. This parameter decides the wheel travel.

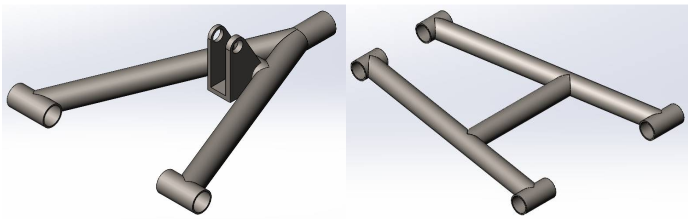


Figure 3(a) front arm
Figure 3(b) rear arm

The parameters decided after a series of iterations are

1. Length of upper control arm= 407mm
2. The length of the lower control arm = 412mm
3. The Inclination of the upper control arm with respect to ground = 18.2 degrees
4. The Inclination of the lower control arm with respect to ground= 14.1 degrees
5. The Distance of shock mount on the lower arm from the pivot point= 298mm
6. The Distance of wheel center axis and pivot point=431mm
7. Motion ratio =0.69

3.3 Wheel Hub and Bearing

The main purpose of this wheel hub is to transmit the power from the driveshafts to the wheel and to support the weight or total mass of the vehicle. It is the only part that holds the wheel. As this wheel hub is the main part that holds the wheel and body of the vehicle together, so it must have a high strength to bear and the material has to be selected as per the capacity of the part. The types of loads acting on the wheel hub are braking force, bump force, and the cornering force. The brake rotor and the wheels are connected to the hub. The diameter of the hub is designed such that bearing is press-fitted into the hub. The selection of bearing is very important because any failure or inefficiency of the bearing does not transmit motion to the wheels. The bearing is chosen by calculating the bearing life and load-bearing conditions. Tapered bearing is used because they can sustain both radial and axial loads. The wheel should be decided before designing the wheel hub because the pitch circle diameter of the hub and rim should complement each other.

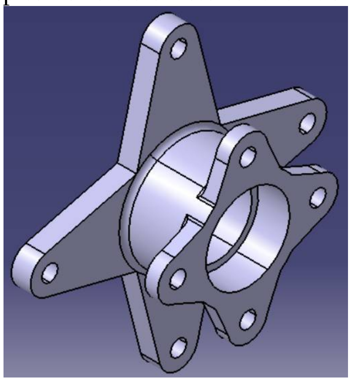


Figure 4: Wheel hub

The specifications on which the hub is designed are:

1) Bearing number :
   a) Front-32205
   b) Rear-32705
2) Pitch circle diameter of the brake rotor =87mm
3) Pitch circle diameter of the rim = 160mm

3.4 Shock Absorbers

We have chosen Fox Float 3 Evol R air shock absorbers that play both the role of spring and the damper. The main reason to choose an air shock absorber is the ability to change stiffness over a wide range. The advantages of air shock absorbers over struts are:

(1) Progressive stiffness (2) High performance (3) Fade free damping.

The stiffness is calculated with the help of the Owner's manual. The parameters like spring rate, ride rate, damping Ratio and sprung mass decide whether the suspension system is stiffer or softer. The softer suspension provides more grip and comfort to the driver but increases the possibility of bottoming out the suspension. Hence, a little stiffer suspension is used.

Table 4: Shock Absorber Parameters

S.NO	**PARAMETER**	**VALUES**	**UNITS**
1	Spring Rate	30,657.6	N/m
2	Motion Ratio	0.69	-
3	Wheel rate	14596.08	N/m^2
4	Ride rate	12255.48	N/m
5	Resonant frequency	1.97	Hz
6	Sprung mass Natural frequency	1.11	Hz

4. EFFECT OF SUSPENSION ON OTHER SUBSYSTEMS

4.1 Suspension and steering

Suspension and steering are closely related to each other because of the knuckle. Ackermann percentage, Turning radius, and the wheel geometry depend on the orientation of inner and outer ball joints of the tie rod. Camber angle increases thrust, which improves cornering characteristics as well as maneuverability. The design of the outer tie rod should be on the same imaginary line passing through the upper and lower ball joint of the knuckle to avoid bump steer.

Castor angle and kingpin inclination increase the steering effort and returnability. Thus, the pinion gear should be designed so that it withstands the steering effort.

All the hard points of the suspension system are given as input in the lotus shark software. The analysis is done to

1. Reduce the Turning radius, which boosts the maneuverability.
2. To Achieve neutral steer condition i.e. 100% Ackermann
3. To observe the changes in the camber angle with respect to rack travel.

Through a series of iterations, we have fixed the orientation of the inner and outer joints of the tie rod. These are the obtained parameters for different rack travel.

Table 5: Effect on suspension and steering parameters due to rack travel

Rack travel (in mm)	Camber Angle RHS	Camber Angle LHS	Ackermann (%)	Turning Radius (mm)
-30.00	0.46	-1.54	94.57	3926.72
-25.00	0.05	-1.68	96.46	4414.78
-20.00	-0.58	-1.79	98.32	5090.72
-15.00	-1.57	-1.88	101.13	7160.47
-10.00	-1.86	-1.95	103.65	11568.29
-5.00	-1.97	-1.99	105.85	23858.77
0.00	-2.00	-2.00	94.57	0.00
5.00	-1.99	-1.97	96.46	23858.77
10.00	-1.95	-1.86	98.32	11568.29
15.00	-1.88	-1.57	101.13	7160.47
20.00	-1.79	-0.58	106.65	5090.72
25.00	-1.68	0.05	105.85	4414.78
30.00	-1.54	0.46	94.57	3926.73

4.2 Suspension and braking

One of the main functions of the braking is to keep the vehicle in the desired position after the brakes are applied. The main problem occurs is the drifting of the vehicle during the application of brakes. The relation between Wheel geometry and vehicle drift has been studied by several iterations. It has been concluded that the castor angle becomes slightly negative and the direction of aligned torque changes. In addition, the steering offset is changed due to the compression of shock absorbers that creates an imbalance.

The Pitching phenomenon can be explained by suspension and braking together. These terms describe the weight transfer when a vehicle accelerates or decelerates. The parameters affecting anti-dive and anti-squat are the orientation of arms in the side view, instantaneous center of the front and rear arms, and the distance of the center of gravity from the ground. The orientation of arms can be changed with the help of roll cage members.

4.3 Suspension and roll cage

The design of the roll cage, especially the nose in front view has significance on the dynamic values of wheel angles. This design is finalized in the online suspension analyzer. The change in camber angle at different nose dimensions is checked and the optimum dimension of the nose is chosen as:

Upper width: 440mm

Lower width: 446mm

Vertical height between upper and lower arms: 167mm

The values of dynamic camber angle with these dimensions with respect to bump travel are:

Table 6: Change in camber angle vs. bump travel

BUMP TRAVEL (In mm)	CAMBER ANGLE (In deg)
-60	-5.09
-40	-3.93
-20	-2.91
0	-2
20	-1.17
40	-0.42
60	0.27

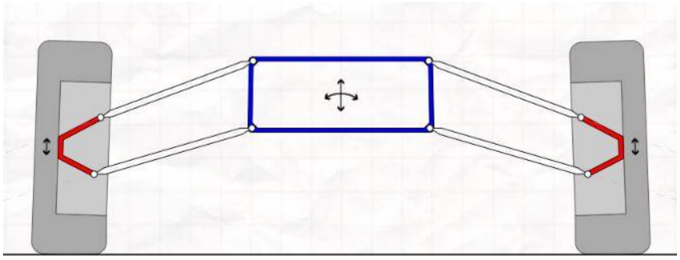


Figure 5: The front view of Control arms and Roll cage nose

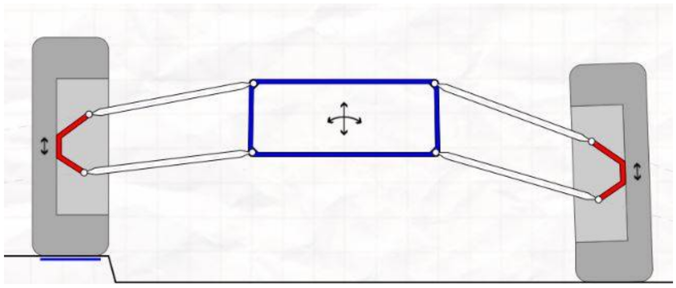


Figure 6: Simulation of a wheel during a bump

5. RESULT

THE IMPORTANT PARAMETERS ACHIEVED THROUGH DESIGNING SUSPENSION SYSTEM ARE:

Table 7: Suspension Parameters

Parameters	Value
Castor Angle	5°
King pin Inclination	12°
Camber Angle	-2°
Length of upper control arm	407mm
Length of lower control arm	412mm
Motion Ratio	0.69
Spring Rate	30657 N/m
Wheel Rate	14596.08 N/m²
Ride Rate	12255.48 N/m
Sprung mass Natural Frequency	1.11Hz

These are the CAD models of the assembled individual suspension components.

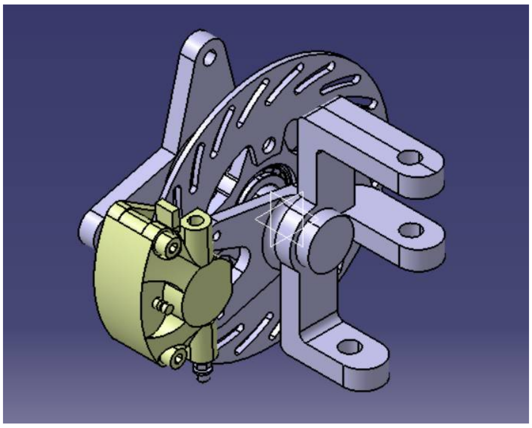


Figure 7: Wheel Assembly

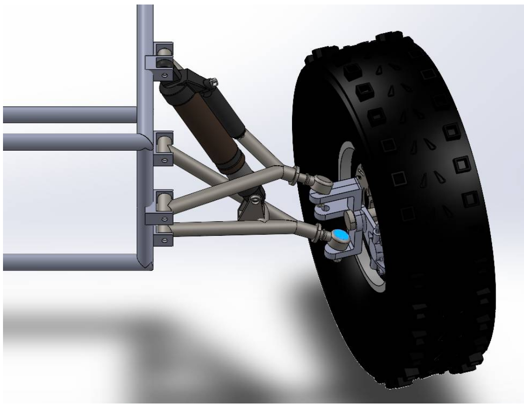


Figure 8: Assembly of Suspension system with roll cage

6. CONCLUSIONS

The Suspension components should be carefully designed and analyzed because most of the suspension parameters fail to be tuned once they are manufactured. From the above iterations, it has been concluded that not all the suspension parameters are obtained through a specific set of calculations. There exist a lot of assumptions and iterations to draw the conclusion. The designs of individual components are performed in Catia V5 software, the assembly of individual components is done in Solid works. The length of the arms and the design of the nose in the front view are done in the online suspension analyzer. The relation between Ackermann percentage, turning radius, rack travel, bump travel and the wheel angles are obtained from lotus shark software, the results obtained prove that the designed suspension system is safe for the vehicle.

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