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Off Road Vehicle Suspension Design and Tuning

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ABSTRACT: The essential component for an All-Terrain Vehicle is suspension system. ATV runs in off road conditions where a good suspension geometry plays a crucial role. The suspension system decides the ride quality and handling of the vehicle along with managing the vehicle's stability and comfort. In this research paper we have identified the general problems with the suspension system of an off road vehicle and have brought a solution to it by the means of a fully adjustable suspension geometry.

KEYWORDS: Double Wishbone, Air Suspension, Independent Suspension, ATV Suspension, Knuckle, Suspension arms.

I. INTRODUCTION

The suspension system of an automobile is one which separates the wheel/axle Assembly from the body. The primary function of the suspension system is to isolate the vehicle structure from shocks and vibration due to irregularities of the road surface. The suspension system of a vehicle refers to the group of mechanical components that connect the wheels to the frame or body. A great deal of engineering effort has gone into the design of suspension systems because of an unending effort to improve vehicle ride and handling along with passenger safety and comfort. In the horse and buggy days, the suspension system consisted merely of a beam (axle) that extended across the width of the vehicle. In the front, the wheels were mounted to the axle ends and the axle was rotated at the centre to provide steering. The early automobiles used the one- piece axle design but instead of being rotated at the centre, it was fix- mounted to the vehicle through springs to provide the cushioning of shock loads from road inaccuracies. The wheels were rotationally- mounted at the axle ends to provide steering. The first springs consisted of thin layers of narrow pieces of strip steel stacked together in an elliptical shape and were called leaf springs. In later installations, leaf springs were replaced by coil springs. In front- engine rear- drive vehicles, the front beam axle was replaced by independently mounted steerable wheels. The wheels were supported by short upper and lower hinged arms holding them perpendicular to the road as did the previous axle beam designs.

The primary functions of the suspension system include maximizing the contact between the tires and the road surface, providing steering stability and good handling, evenly supporting the weight of the vehicle (including the frame, engine, and body), and ensuring the comfort of passengers by absorbing and dampening shock. Your vehicle's suspension system works hard to withstand a considerable amount of stress compared to other major vehicle systems.

But also our main purpose is to give more comfort to the driver and a vehicle body by change the air pressure of shock absorber.

Although the detailed investigations have been carried out in this work on the dynamic performance of the off road vehicle, some areas appear to invite productive future work, and these are summarized below

1. The model of tracked vehicle formulated and taken for analysis in this dissertation work is sufficiently accurate. However the vehicle can be modelled using additional degrees of freedom of each wheel (forward and lateral slip of wheel) and model for wheel/track terrain interaction.
2. Road input in this dissertation work is for sinusoidal and transient road excitations. However model with random input would give realistic dynamic characteristics (shock and isolation) of an off road vehicle.Road Isolation – is the vehicle ability to absorb or isolate road shock from the passenger compartment.

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Basic functions the suspension system should perform are

1. Maintain correct vehicle ride height.
2. Reduce the effect of shock forces.
3. Maintain correct wheel alignment.
4. Support vehicle weight.
5. Keep the tyres in contact with the road.
6. Control the vehicle's direction of travel.

II. SYSTEM DESIGN CALCULATIONS (DATA SHOWN IS FROM OUR PROTOTYPE ATV AS EXPERIMENT FINDINGS)

1. Motion Ratio

Motion ratio in suspension of a vehicle describes the amount of shock travel for a given amount of wheel travel. Mathematically it is the ratio of shock travel and wheel travel. The amount of force transmitted to the vehicle chassis reduces with increase in motion ratio.

- Fox Float 3 Evol R suspension travel – 5.3 inches = 134.62mm
- Motion Ratio Front = spring displacement / wheel displacement = 10.16 / 14 = 0.72
- Motion Ratio Rear = spring displacement / wheel displacement = 8.44 / 11.8 = 0.71

2. Weight Distribution

Weight distribution is one of the important aspects of suspension tuning as the car's weight distribution affects car handling, acceleration and traction...Ideally, the front-to-rear weight distribution on the left side of the car should be the same as the front-to-rear weight distribution on the right side

- Kerb weight = 148.28 kg
- Gross weight = 218.28 kg
- Sprung weight = 148.28 kg + 70 kg = 167.4 kg 170 kg
- Unsprung weight = 50.88 kg

Directional Stability – is the ability of the vehicle to maintain a directed path.
Returnability – is the ability of the vehicle to return the front wheels to straight ahead after turning.
Tracking – is the path taken by the front and the rear wheels.
Cornering – is the ability of the vehicle to travel a curved path.

- W = Sprung mass
- L = Distance between Centre of gravity to rear wheel centre = 551.43 mm
- B = Wheel base = 54 inch
- Front wheel weight Rf = WL/B

= [(170) × (551.43)] / 1371.6
= 68.34 kg

- On single wheel = 34.17 kg
- Rear wheel weight Rr = [1 – (L / B)] × W

= [1 – (551.43 / 1371.6)] × 170
= 101.66 kg

- On single wheel = 50.83 kg
- Weight distribution Ratio = Front axle weight : Rear axle weigh

= 1: 1.48

3. Rebound Travel

The downward travel of the tire and wheel that extends the spring and shock absorber is called rebound, or extension. When the spring is deflected, it stores energy. Without shocks and struts the spring will extend and release this energy at an uncontrolled rate.

- Front = Suspension travel / Motion ratio =134.62 / 0.72

= 186.97 mm

- Rear = Suspension travel / Motion ratio

= 134.62 / 0.71
= 189.60 mm

Rebound Travel is set 33% of Total Wheel Travel.

	Bound Travel	Rebound Travel
Front	125.27 mm	61.7 mm
Rear	127 mm	62.6 mm

4. Spring Rate

Spring rate is a key factor in choosing the right springs for your suspension system. Spring rate is defined as the amount of force it takes to compress a spring one inch. A 200 lbs. /in. linear spring, for example, will compress one inch when a 200-pound load is placed onto it.

5. Stiffness

In terms of the driver's oscillatory comfort, the bus suspension system should have a spring of small stiffness and a shock absorber with a low damping coefficient. The suspension system is one of the main vehicle systems, significant for the realisation of comfort, stability and safety parameters.

- **Spring Rate / Stiffness**

K (front) = 4 × $(\pi)^2$ × $(fr)^2$ × $(MR)^2$ × (M) × (g)

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Where, fr = Ride Frequency
MR = Motion Ratio
M = Mass on one wheel
g = Gravitational Force

- K (front) = 4 × (π)² × (2.2)² × (0.72)² × (34.17) × (9.8)
  = 33169.66 N/m
  = 33.16 N/mm
- K (rear) = 4 × (π)² × (2.5)² × (0.71)² × (50.83) × (9.8)
  = 61958.74 N/m
  = 61.95 N/mm

6. Wheel Rate

It is basically the Spring Rate multiplied by the motion ratio squared. The motion ratio is the ratio between how much the spring is compressed compared to how much the wheel is actually moved. For example if the spring only compresses 0.6 inches when the wheel is moved 1 inch, that would be a . 6 motion ratio.

- Kw (front) = K × (MR)² × ACF
  Where, ACF = Angle Correction Factor

- Kw (front) = (33.16) × (0.72)² × (cos 29.78)
  = 14.9 N/mm

- Kw (rear) = (61.95) × (0.71)² × (cos 22.39)
  = 28.57 N/mm

7. Tire Rate

- Kt = (Max load on tyre by falling from 2 metre) / [(Unloaded radius of tyre) – (Static load radius of tyre)]
- For maximum load using velocity equation

x = Vo + ½ a t²
Where, x = distance
a = acceleration (9.8 m/s²)
t = time
Vo = initial velocity

- 2 = 0 + ½ (9.8) t²
- t = 0.6388 sec

- V² - Vo² = 2ax
- V² = 2ax
- V² = 2 (9.8) (2)
- V² = 39.2
- V = 6.26
- F = Δm / t

Where, Δm = momentum
- F = (m) (v) / t
- F =(220) × (6.26) / (0.6288)
- F = 2155.91 N
- Unloaded Radius = [23 × 25.4] / 2
  = 292.1 mm

- Static Load Radius = [(23) × (25.4) × (0.98)] / 2
  = 286.258 mm

- Kt = 2155.91 / (292.1– 286.258)
  = 369.03 N/mm

8. Damping Ratio

The damping ratio is a dimensionless measure describing how oscillations in a system decay after a disturbance. Many systems exhibit oscillatory behaviour when they are disturbed from their position of static equilibrium. A mass suspended from a spring, for example, might, if pulled and released, bounce up and down.

- Damping Ratio (δ) = [(Wn)² - (Wd)²] / (Wn)

Here, Wn = 2 π fn
Wn (front) = 2 π (2.2) = 13.82
Wn (rear) = 2 π (2.5) = 15.70
Wd = 2 πfd

- fd = { (187.8) × [(Kr) / (m)]½ } / 60
- Fd (front) = [187.8 × (14.32 / 34.17)½] / 60
  = 2.02
- Wd (front) = 2π (2.02) = 12.7
- Fd (rear) = [187.8 × (26.77 / 50.83)½] / 60
  = 2.27
- Wd (rear) = 2π (2.27)
  = 14.26
- δ (front) = { [(13.82)² - (12.7)²]½ } / 13.82

δ (front) = 0.3943
- δ (rear) = { [(15.70)² - (14.26)²]½ } / 15.70

δ (rear) = 0.4183

9. Angles of Calculation

- Roll Centre Height:-

The roll centre height is an important characteristic for independent suspensions. The roll centre height has two effects on vehicle dynamics. (Front = 17.4 inches, Rear = 16.9 inches)

- Camber Angle:-

Camber angle is the angle made by the wheels of a vehicle; specifically, it is the angle between the vertical axis of the wheels used for steering and the vertical axis of the vehicle when viewed from the front or rear. (Camber Angle = -1˚)

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- Caster Angle:-

The caster angle is the angular displacement of the steering axis from the vertical axis of a steered wheel in a car, motorcycle, bicycle, other vehicle or a vessel, measured in the longitudinal direction. It is the angle between the pivot line (in a car an imaginary line that runs through the centre of the upper ball joint to the centre of the lower ball joint) and vertical. (Caster Angle = +3˚)

- Scrub Radius:-

The scrub radius is the "lever arm" of longitudinal forces applied at the contact patch (when braking). On the front suspension, a positive scrub radius gives stability because it causes toe out when braking and toe in when accelerating. (Scrub Radius = 21mm)

III. SUSPENSION TUNING

- **Suspension Stiffness Setting**

In our project, we use Semi-Active Suspension system. So we can change the stiffness of shock absorber (softer or stiffer) manually by air filling pump of suspension.

- Soft Shock Absorber:-

Soft Suspension. Like a firm suspension a soft one is exactly what it sounds like, the suspension is softer or less rigid. This gives the vehicle a much smoother ride, even on a bumpy or rough road due to the fact that the suspension system has much more give to it.

- Stiff Shock Absorber:-

If the suspension is stiffer, it's going to push the wheel harder on the road offering enough traction, which allows the driver to accelerate faster without slipping on wheels. The vehicle is meant for a sporty ride and the track is not going to bumpy, so it's simply to choose a stiffer suspension.

- **Suspension Rebound Setting**

- Toe:-

Toe out is where the back edge of the front two tyres is closer together than the front edge of the same tyres. (Toe = 0 mm or 0˚)

- Centre of gravity Height:-

Centre of gravity of a freely suspended body always lies vertically below the point of suspension. If you suspend an object from any point, let it go and allow it to come to rest, the centre of gravity will lie along a vertical line that passes through the point of suspension. (C.G. Height = 570 mm)

Rebound damping regulates the speed at which your fork or shock recovers, or bounces back, from an impact and returns to its full travel. Much like a compression circuit, rebound damping relies on oil moving through a circuit to regulate the speed at which the suspension extends after being compressed.

IV. COMPUTER SIMULATIONS AND ANALYSIS

Computer simulation is a key part of the automotive development process. Lotus Engineering Software has been developed by automotive engineers, using them on many powertrain and vehicle projects at Lotus. The philosophy under-pinning Lotus Engineering Software is to offer simulation tools which enable the user to generate models very quickly, using a mixture of embedded design criteria and well-structured interface functionality

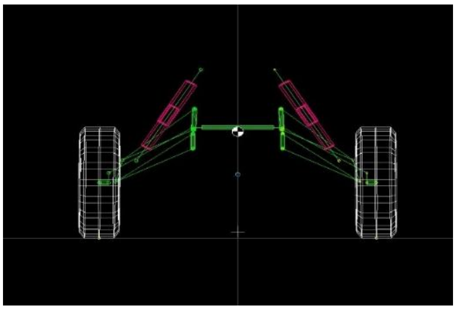

Fig 1 Camber Gain

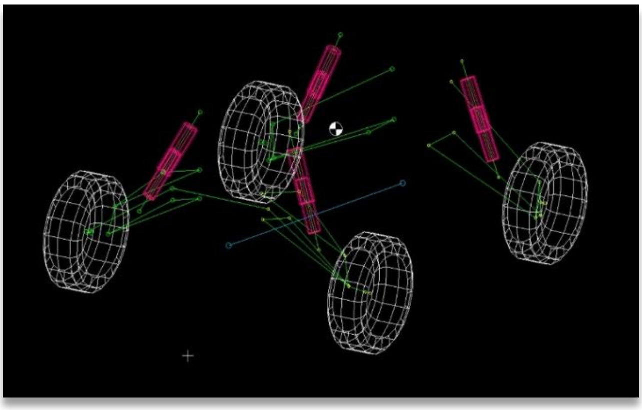

Fig 2 Suspension Kinematics

SolidWorks: 3D Modelling Software with parametric construction. SolidWorks is computer-aided design (CAD) software owned by Assault Systems. It uses the principle of parametric design and generates three kinds of interconnected files: the part, the assembly, and the drawing.

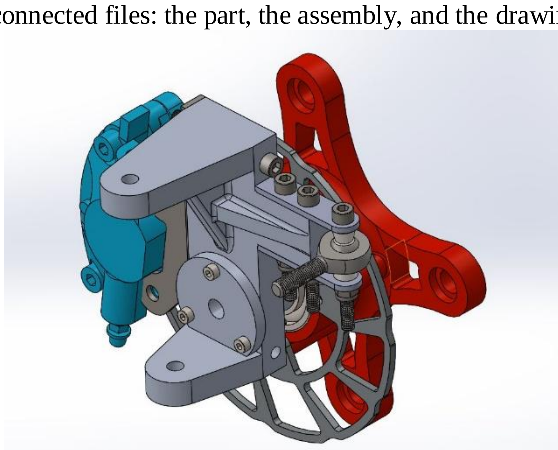

Fig 3 Wheel Hub

Solid Works is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. It's great software that can be used for a variety of purposes in different industries. SOLIDWORKS is a very productive 3D CAD software tool, with its integrated analytical tools and design automation to help stimulate physical behavior such as kinematics, dynamics, stress, deflection, vibration, temperatures or fluid flow to suit all types of design. For final product designing we made 3D model in SOLIDWORKS Software, in which we made different individual components and finally we made assembly of different components.

Ansys; Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analysing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes.

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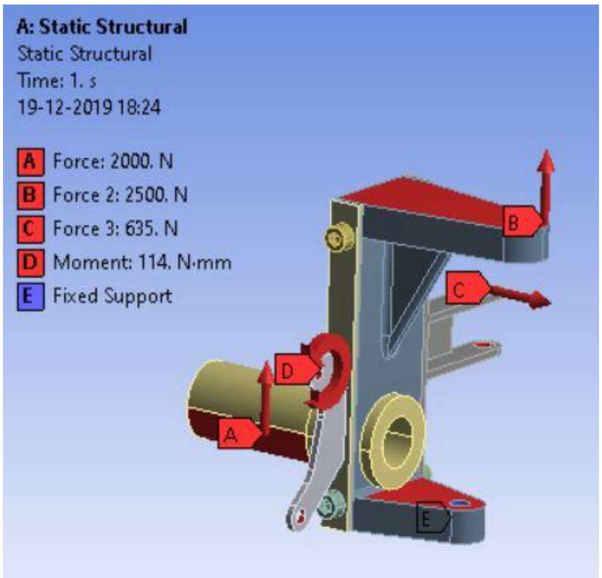

Fig 4 Loadingcase

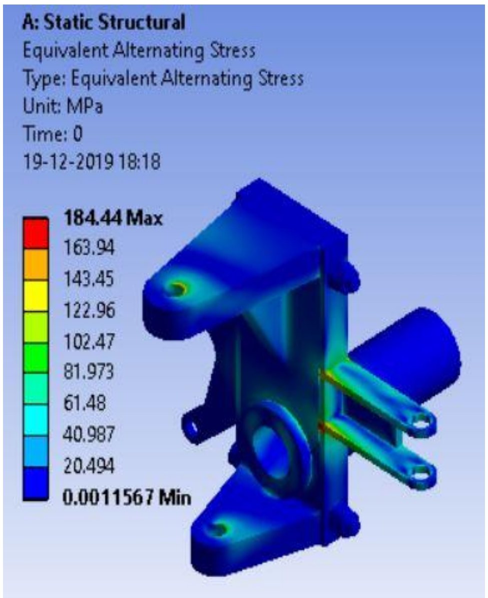

Fig 5 Equivalent Altering Stress

This is the picture we took for better understanding of working of the FOX EVOL shock absorbers.

Fig 6 Suspension service

Fig 7 Prototype

Fig 8 Shows the operation ability even at high angles

V. CONCLUSION AND FUTURE WORK

- **Conclusion**

In order to keep the options open for the changes required in the camber, toe, etc. characteristics of the tyre assembly, we have used double wishbone suspension system in the front. It also provides us the advantage of a more compact assembly along with a more rigid and flexible motion. It is also easy to assemble and disassemble. It also is the easiest in terms of defining the mounting points for the arms and the shock absorbers.

In the rear we have used the H-Arm suspension geometry to give us all the properties of the wheel travel. This geometry also allows us to give adequate amount of space to accommodate the drive shafts. We have used a camber link along with the H-Arm to set the camber and also to keep the rear knuckle perfectly straight to get a linear wheel travel.

Along with both the suspension geometries, we have used Fox Air Suspensions which allow us to fine tune the shock absorbers as we like to obtain the perfect value of Stiffness, rebound and damping rate as required by the driver and the terrain the vehicle has to go on.

- **Future Scope**

While further working on the vehicle, we will be trying to improve the smoothness and the flexibility of the vehicle. We will be trying to reduce the weight of the assemblies. We will make the assemblies more compact and increase the impact resistance.

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