Design Review of Suspension Assembly of a BAJA ATV

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Abstract - All Terrain Vehicle is designed to move through all terrain. Suspension system of this vehicle should be strong to provide better ride and handling with better comfort. Independent suspension systems are required for this purpose. It is designed using LSSA (Lotus Shark Suspension Analysis). After designing in Lotus, with the hard points the A-arms, front and rear uprights are then designed in CATIA and analyzed it by using ANSYS. It is the system that connects the wheels with chassis by means of an assembly, which provides firmness necessary to compensate shocks from roads. Suspension system defines roll/body angle, effortless steering, camber characteristics and many other factors. The suspension system must be quite rigid in order to bear sudden shocks due to drop, sudden dump etc. The suspension systems of vehicle support in maneuverability and driver’s comfort. The suspension designing should withstand ruggedness, driver’s fatigue-less driving.

Key Words: Suspension system, Lotus, Shocks, Double wishbone.

1. INTRODUCTION

The primary functions of a vehicle’s suspension systems are to isolate the structure and the occupants from shocks and vibrations generated by the road surface. It is obvious that a suspension system must be able to withstand the loads acting on it. These forces may be in the longitudinal direction such as acceleration and braking forces, in the lateral direction such as cornering forces, and in the vertical direction.

The suspension system of BAJA vehicle is to absorb vibration due to irregularities of road conditions that require greater stiffness and tough/rigid body. Greater stiffness creates fatigue to the driver. So springing action will be the major factor behind designing. The choice of right type and its major benefit will play a major role in winning. So it is equally important to specify the correct type and validate it in software. Furthermore, it also designed to maximize the friction between tire contact patch and the road surfaces to provide vehicle stability under any circumstance associated with accelerating, braking, loaded or unloaded, uneven road, straight line or cornering. The suspension system significantly affects ride and handling of the vehicle that is ‘vibrational’ behavior including ride comfort, directional stability, steering characteristics and road holding. Generally, suspension system can be broadly classified as dependent and independent types.

The factor which primarily affect the choice of suspension type at the front or rear of the vehicle are the engine location and whether the front wheels are driven/undriven and steered/unsteered.

Independent suspension (i.e. double wishbone, McPherson and multilink) leads to better ride and handling capabilities. It is important to analyze the suspension systems that have been designed to predict the behavior of the system than followed with improvements.

Out of these available design, double wishbone type suspension is selected which gives adequate space for wheel assembly, better control over design characteristic and flexibility to designer in terms of performance variables.

1.1 Objective of Suspension System

It is important to analyze the suspension systems that have been designed to predict the behavior of the system than followed with improvements.

The suspension must be properly designed because it is a crucial subsystem in vehicle in order to:

- Carry the weight of vehicle and also its weight (unsprung weight).
- Keep the wheel perpendicular to the road for maximum grip resultant good ride and handling performance.
- Take the forces for accelerating or braking the vehicle.
- Ensure that steering control is maintained during maneuvering.
- Take the forces involved when cornering the vehicle.

1.2 Need of Double Wishbone Suspension System

In automobiles, a double wishbone (or upper lower A-arm) suspension is an independent suspension design using two (occasionally parallel) wishbone-shaped arms locate the wheel. Each wishbone or arm has two mounting points to the chassis and one joint at the knuckle. The shock absorber and coil springs mount to the wishbone to control vertical movement. Double wishbone design allow the engineer to carefully control the motion of the wheel throughout suspension travel, controlling such parameters as camber angle, caster angle, toe pattern, roll center height, scrub radius and more.
1.3 Concepts Related to Suspension System

Camber: 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 can have both negative as well as positive orientation. Camber is considered positive if the top of the wheel leans outwards and negative if the top of the wheel leans inwards.

Castor: It is the angle between the pivot line (in a car an imaginary line that runs through the center of the upper ball joint to the center of the lower ball joint) and vertical.

King Pin Inclination: Kingpin inclination is defined as the angle at which kingpin axis is inclined to the vertical axis passing through the wheel center. Kingpin angle affects the performance of the car when the wheels are steered. More the kingpin angle more the car will lift when steered. When the kingpin axis is extended up to the ground, it intersects the ground at a particular point. The distance of that point from the center of wheel contact patch is called scrub radius. Scrub radius increases the wear of the tire but some amount of negative scrub radius is required so that the wheel purely rolls when steered.

Roll Center: The Roll Centre of a suspension system is that point in the transverse plane of the axles, about which the sprung mass of that end of the vehicle will roll under the influence of centrifugal force.

Toe: Toe is final parameter used to describe a vehicle’s alignment. Toe is the symmetric angle that each wheel makes with the longitudinal axis of the vehicle, as a function of static geometry, kinematic and compliant effects. Tire wear is heavily dependent on the toe distances. Dynamic factors induce change in toe, which lead to two conditions—toe in and toe out. In rear wheel drive cars, increased front toe in provides greater straight-line stability at the cost of some sluggishness in steering response.

Table - 1.1: Essential parameters related to suspension system

<table>
<thead>
<tr>
<th>S.N. O.</th>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Wheelbase</td>
<td>56°</td>
</tr>
<tr>
<td>2.</td>
<td>Track-width</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Front</td>
<td>52°</td>
</tr>
<tr>
<td></td>
<td>Rear</td>
<td>52°</td>
</tr>
<tr>
<td>3.</td>
<td>Ground Clearance</td>
<td>13°</td>
</tr>
<tr>
<td>4.</td>
<td>Kingpin Inclination</td>
<td>18.16 degree</td>
</tr>
<tr>
<td>5.</td>
<td>Kingpin Offset(ground)</td>
<td>8.408 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.N. O.</th>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.</td>
<td>Castor Angle</td>
<td>0 degree</td>
</tr>
<tr>
<td>7.</td>
<td>Camber</td>
<td>0 degree</td>
</tr>
<tr>
<td>8.</td>
<td>Tire Dimension</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Front</td>
<td>21*7R10</td>
</tr>
<tr>
<td></td>
<td>Rear</td>
<td>22*8R10</td>
</tr>
</tbody>
</table>

Table - 1.2: Final geometry parameter

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper wishbone</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>354.9 mm</td>
</tr>
<tr>
<td>Angle</td>
<td>25.2 degree</td>
</tr>
<tr>
<td>Lower wishbone</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>385.04 mm</td>
</tr>
<tr>
<td>Angle</td>
<td>24.9 degree</td>
</tr>
<tr>
<td>Roll center height</td>
<td>226.14 mm</td>
</tr>
</tbody>
</table>

2. DESIGN METHODOLOGY

The design is completed in LOTUS SHARK suspension designing software system. The calculations are made concerning the analysis papers. The design is formed keeping the anti-dive properties to the minimum to stay the ATV stable altogether conditions. Before designing the suspension of vehicle we have concentrate upon a number of the essential parameters of the vehicle needed for it.

LOTUS Shark suspension analysis tool is employed for initial calculation of the vehicle. 3D moving models are often creating and change in LOTUS Shark Suspension Analysis (LSSA). Using LSSA hard points are drawn and graphical and numerical values are found out. This modelling approach permits user to form their own suspension models and work on them simply. The changes in any parameters can be find out camber angle, toe angle are often displayed diagrammatically against motions like roll motion, bump motion, steering motion. many parameters are thought of to
induce the hard points of the suspension system like damping magnitude relation, sprung and un-sprung weight, spring rate, camber angle, caster angle, roll center, wheelbase, track dimension, toe angle, ground clearance. So before coming up with in LSA we've got design considerations:

1) Kingpin and caster angle are kept in such a way that they'll compensate every others camber gain well, by providing their individual function.

2) A positive king pin angle is kept to assist in steering the vehicle. Roll center below CG to avoid unwanted force.

3) Front ride frequency is more than rear portion.

4) Roll axis inclined towards front portion to present understeer characteristic to the vehicle.

5) Front double wishbone unequal for Camber angle.

We have taken Damper to upper wishbone for the front suspension and damper to lower H-arm in rear suspension system. We have design by using these parameters and additionally by checking various properties like roll motion, roll center, bump motion, steering motion. These properties are controlled by controlling the camber, caster, toe, kingpin angle etc.

### Front Suspension

Double wishbone suspension system of unequal length and parallel was implemented for front suspension additionally referred to as short long arms (SLA). We tend to finalize the form of wishbone to be an arms because it will distribute stresses over the members effectively and in a very proper method. Upper wishbone is shorter than lower wishbone. The advantage of getting completely different lengths is that once the vehicle takes a flip a negative camber is induced that will increase the stability.

### Rear Suspension

It consists of equal H-arms and I-arm design. Independent H-arm are widely accepted as camber changes is simply eliminated and controlled. One end is connected to the chassis and alternative end is connected to the knuckle. A H-arm provides great deal of travel and principally equal the front suspension. At rear side the camber angle and the toe angle can the zero. As we are having damper to lower arm in rear side therefore the upper arms are of I-shape and therefore the rear lower arms can of h-shape. As we've camber angle 0° that makes our front suspension equal and parallel. we'll mount the spring within the higher stiffness which is able to be tilted towards the axle side.

### Uprights

Upright is design by CATIA software by using the right tire dimensions. It’s designed in such a way that it may hold the upper and lower pivot points of the arms and therefore the
output shaft long with the hub and brake callipers without any difficulties. After this it's tested by collecting all the remaining elements of the suspension system.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Steel AISI 1018 Properties</th>
<th>Steel AISI 4130 Chromoly alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7861.1 kg/m³</td>
<td>7861.1 kg/m³</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>4398.85 x 10⁵ N/m²</td>
<td>6701.70 x 10⁵ N/m²</td>
</tr>
<tr>
<td>Yield Tensile Strength</td>
<td>3702.48 x 10⁵ N/m²</td>
<td>4350.59 x 10⁵ N/m²</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>199.94 x 10⁵ N/m²</td>
<td>2047.74 x 10⁵ N/m²</td>
</tr>
<tr>
<td>Bulk Modulus</td>
<td>1399.63 x 10⁵ N/m²</td>
<td>1399.63 x 10⁵ N/m²</td>
</tr>
<tr>
<td>Elongation Break</td>
<td>15%</td>
<td>25.5%</td>
</tr>
</tbody>
</table>

Table 2.1: Upright Material Properties

3. MATERIAL SELECTION

Material consideration for the wishbone becomes the most primary need for design and fabrication. The strength of the material should be well enough to withstand all the loads acting on it in dynamic conditions. The material selection also depends on number of factors such as carbon content, material properties, availability and the most important parameter is the cost.

4. IMPACT FORCES CALCULATION OF FRONT SUSPENSION SYSTEM OF ATV BAJA VEHICLE

4.1. Impact force determination by speed limit (for static analysis)

(According to the rule book. The maximum speed of the car is assumed to be 60km/h around 16.66m/s)

For the elastic collision,

\[ W = \frac{1}{2} m v_{\text{final}}^2 - \frac{1}{2} m v_{\text{initial}}^2 \]  

Where,

\[ W_N = \text{net work done on account of an inelastic collision.} \]

\[ W_N = -\frac{1}{2} (m) (v^2)_{\text{initial}} \]  

But,

\[ W_N = \text{Impact force} \times d \]  

Where \( d \) is the distance travelled during impact.

(It is considered that for static analysis, the vehicle comes to rest 0.1 seconds after impact. Therefore, for a vehicle which moves at 16.66m/s (or 60km/h), the travel of the vehicle after impact is 1.66m from equation (1), (2) and (3), we get).

4.2. Impact force determination by Acceleration limit

\[ \text{Force} = m \times a \]

Where \( m = 261.5 \) kg and \( a = 7.9 \times 9.81 \text{m/s}^2 \)

5. CALCULATIONS

Total Sprung mass (\(S_m\)): 116 kg
Total Unsprung mass (\(US_m\)): 65 kg
Total Weight: 181 kg
Front track width (\(F_{tw}\)): 52 inches
Rear track width (\(R_{tw}\)): 52 inches
Static ride height (\(S_{rh}\)): 13 inches
Tire diameter (\(T_d\)): 22 inches
Ride frequency front (\(R_f\)): 2 Hz
Ride frequency rear (\(R_r\)): 2.5 Hz
5.1 Spring Constant:
\[ w = \sqrt{\left( \frac{k}{m} \right)} \]
where \( w \) = amplitude
\( k \) = spring constant
\( m \) = sprung mass
We also know that
\[ w = 2\pi f \]
where \( f \) = ride frequency
on equating both the equations we get,
\[ k = 4\pi^2 mf^2 N/m \]
using the above formula, the spring constants for the front and rear suspension system are calculated. Quarter body analysis of the sprung mass is done so that sprung mass acting on each wheel is determined.
The weight distribution according to the calculation is front: rear = 42:58.

Front spring constant:
Entire sprung mass \( (S_m) \) = 116 kg
Front sprung mass = 48.72 kg
Mutual mass \( (M_t) \) = 48.72 x 1.7 = 82.824 kg
The load acting on each wheel at front \( (m_1) \) = 41.412 kg
k = 4\pi^2 m_1 f^2
k = 4 x \pi^2 x 41.412 x 2^2
k = 6532.89 N/m or 6.532 N/mm

Rear spring constant:
Entire sprung mass \( (S_m) \) = 116 kg
Rear sprung mass = 116 x 0.58 = 67.28 kg
Mutual mass \( (M_r) \) = 114.37 kg
The load acting on each wheel at rear \( (m_2) \) = 57.18 kg
k = 4\pi^2 m_2 f^2
k = 4 x \pi^2 x 57.18 x 2.5^2
k = 14094.29 N/m or 14.094 N/mm

5.2 Wheel rate
Wheel rate = spring rate x (motion ratio)^2
Front wheel rate = 6.532 x (0.5)^2 = 1.63 N/mm
Rear wheel rate = 14.094 x (0.7)^2 = 6.90 N/mm

5.3 Roll gradient:
\[ f_R = \frac{-W_v x H_{cg}}{G_g RR_{ff} + RR_{fr}} \]
Where,
\( H_{cg} \) = cg to Roll axis distance (m)
\( W_v \) = Vehicle weight (N)
\( F_R/G_g \) = Roll gradient from ride springs (degree/g)

Front Roll Rate:
\[ RR_{ff} = \frac{3.14*(t_r)^2K_{lf}K_{rf}}{180*(W_{rf}+W_{rr})} \]

6. ANALYSIS AND RESULTS

Fig. 6.1: Suspension A-arm (Total Deformation)
Fig. 6.2: Suspension A-arm (Equivalent Stress)
Table 6.1: A-Arm Material Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>1.4255e+065 mm³</td>
</tr>
<tr>
<td>Mass</td>
<td>1.119 kg</td>
</tr>
<tr>
<td>Scale Factor Value</td>
<td>1</td>
</tr>
</tbody>
</table>

**Fig. 6.3**: Suspension A-arm (Maximum Shear Stress)

**Analysis Details:**
Material: AISI 4130 Chromoly
OD*Thickness: 29.2*1.65 mm
Bending Stiffness: 2764 Nm²
Bending Strength: 438 Nm
Load Applied: 3G
Maximum Stress: 103.41 MPa
Maximum Deformation: 0.37 mm

**Fig. 6.4**: Suspension mounting (Total Deformation)

**Analysis Details:**
Material used: AISI 4130 Chromoly metals
Maximum Stress: 23 MPa

**Fig. 6.5**: Suspension mounting (Equivalent Stress)

**Analysis Details:**
Material: AISI 4130 Chromoly
OD*Thickness: 29.2*1.65 mm
Bending Stiffness: 2764 Nm²
Bending Strength: 438 Nm
Load Applied: 3G
Maximum Stress: 103.41 MPa
Maximum Deformation: 0.37 mm

**Table 6.1**: Result of Simulation and Calculations

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll Rate</td>
<td>Front</td>
</tr>
<tr>
<td></td>
<td>Rear</td>
</tr>
<tr>
<td>Wheel</td>
<td>Front</td>
</tr>
</tbody>
</table>

**Fig. 6.6**: Shock absorber mounting (Total Deformation)

**Analysis Details:**
Poisson's Ratio: 0.29
Thickness: 5mm
Maximum Principal Stress: 2.46 MPa
Equivalent Stress: 5.89 MPa

**Fig. 6.7**: Suspension Knuckle (Total Deformation)

**Analysis Details:**
Material: Aluminium 6061
Yield Strength: 705MPa
Load Applied: 3G
Maximum Stress: 105.7 MPa
Maximum Deformation: 0.37 mm

**Fig. 6.8**: Suspension Knuckle (Equivalent Stress)
CONCLUSION

After initial testing of the sub-systems designed, it was observed that the systems fulfilled their individual performance expectations. The suspension system has near optimum steer characteristics. The research work concludes the safe, comfortable and balanced wheel assembly arrangements for BAJA ATV. The calculations helped to achieve better under steer all-terrain vehicle which is able to handle tough conditions. The suspension composed of the hydraulic dampers and springs provides the sturdiness along with the flexibility to absorb shocks and bumps. The material 4130 Chromoly withstand enough for all-terrain conditions leading to conclusion for inexpensive, weld ability material. The calculations describe values of roll rate at front, wheel rate and coil rate along with wheel frequency. In this way, the design of suspension system is successfully completed and serves as ground for further research on said topic.

<table>
<thead>
<tr>
<th>Rate</th>
<th>Rear</th>
<th>6.90 N/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion</td>
<td>Front</td>
<td>0.5</td>
</tr>
<tr>
<td>Ratio</td>
<td>Rear</td>
<td>0.7</td>
</tr>
<tr>
<td>Spring</td>
<td>Front</td>
<td>6.532 N/mm</td>
</tr>
<tr>
<td>Constant</td>
<td>Rear</td>
<td>14.094 N/mm</td>
</tr>
</tbody>
</table>

REFERENCES

[9] https://www.google.com

Manufacturability/Machining

It is very important for engineers to design for manufacturability. In other words, the components, parts or the entire assembly being designed need to be relatively easy to manufacture. If a component can be easily manufactured, it means the productions costs can be taken to a minimum and production speed can be improved. For this project it was taken into consideration to design the components of the suspension to be easy to manufacture. In other words, most of the parts can be fabricated with basic tools. The upright is one of the most important parts of this system since it connects all parts of the suspension together. Thus it was important for our team to come up with an efficient, strong, light weight model. The material 4130 Chromoly withstand enough for all-terrain conditions leading to conclusion for inexpensive, weld ability material. The calculations describe values of roll rate at front, wheel rate and coil rate along with wheel frequency. In this way, the design of suspension system is successfully completed and serves as ground for further research on said topic.