Selection, Modification and Analysis of Suspension System for an All-Terrain Vehicle

Eshaan Ayyar, Isaac de Souza, Aditya Pravin, Sanket Tambe, Aqleem Siddiqui & Nitin Gurav
E-mail : eshaan004@gmail.com, isaacd68@gmx.com, adityaraman91@gmail.com, sank_200956@yahoo.com

***Abstract* - The real pleasure of driving for an off-road enthusiast can be described as the thrill of the terrain coupled with a capable machine to handle the terrain. However, this pleasure can be derived only when the comfort level of the driver is maintained. Thus, it is concluded that the suspension system (which is responsible for providing a comfortable ride quality to the driver) is one of the most important sub-systems to be designed. This paper aims at selecting, modifying, analyzing and fabricating a suspension system capable of handling rough terrains while maintaining the ride quality.**

I. INTRODUCTION

Suspension system is the term given to the *system of springs, shock absorbers and linkages that connect a vehicle to its wheels*.When a tire hits an obstruction, there is a reaction force and the suspension system tries to reduce this force. The size of this reaction force depends on the unsprung mass at each wheel assembly. In general, the larger the ratio of sprung weight to unsprung weight, the less the body and vehicle occupants are affected by bumps, dips, and other surface imperfections such as small bridges. A large sprung weight to unsprung weight ratio can also impact vehicle control.

The main role of suspension system is as follows:

- It supports the weight of the vehicle
- Provides a smoother ride for the passengers
- Protects the vehicle from damage
- Keeps the wheels firmly pressed to the ground for better traction
- It isolates the vehicle from road shocks

There are three basic components in any suspension system:

- Springs
- Dampers
- Anti-sway bars

The following types of suspension systems are generally available in the market:

1. Mechanical Suspension System:

i) Independent Suspension

- Leaf Spring Suspension
- MacPherson Suspension
- Wishbone Suspension

ii) Dependent Suspension

- Rigid Axle Suspension

2. Electric Suspension System

3. Magnetic Suspension System

II. SELECTION OF SUITABLE SUSPENSION SYSTEM

The selection of the suspension system which will best satisfy the requirements of an ATV was carried out. Out of the many available suspension systems in the market, the *Double Wishbone Suspension System* was selected for the ATV. This selection was done based on the following basic parameters:

1. Load bearing capacity
2. Flexibility
3. Cost
4. Technical aspects: Camber, Stiffness, Rolling
5. Availability of parts and components

III. DESIGN

The design procedure for the chosen suspension system is divided into two stages:

1. Primary design:

- Basic design and development of Suspension System components

- Modified design parameters based on approximation of Dynamic Conditions
- Static testing and analysis

2. Secondary design:

- Mathematical modeling of finalized concept ATV
- Dynamic testing and analysis
- Modification of Design Parameters based on Dynamic Testing results

The following components are to be designed:

- Suspension Spring
- Wishbones
- Knuckle

Design procedure for the components of Suspension system is dependent on the suspension geometry (as shown in Fig.1 and Fig.2); found out by taking into considerations the design constraints.

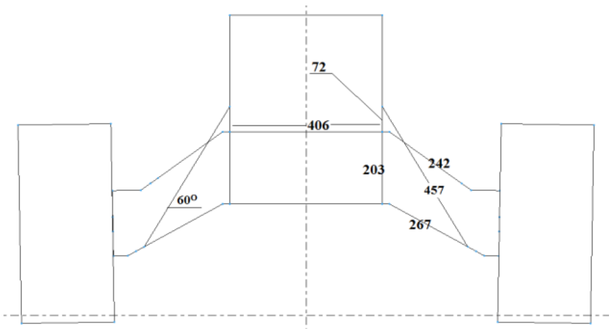

Fig.1 Front suspension geometry

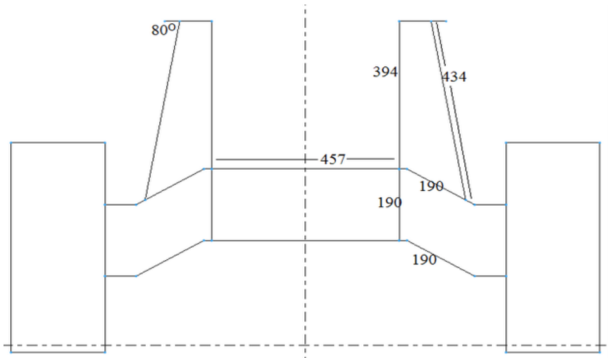

Fig.2 Rear suspension geometry

Design of suspension spring

Assumptions made:

- Sprung mass = 260 kg(approx.)
- Factor for static to dynamic conditions : 2.5
- According to the mass distribution of 60:40 (Rear: Front)
- Mass per wheel (Front) = 50 kg
- Mass per wheel (Rear) = 80 kg

1) Front spring

Angle of inclination of the strut = 60 (from horizontal)

Point of attachment of strut = 10” (254 cm) from chassis end ….(from suspension geometry)

Reaction force acting from the ground on the wheel = (Mass per wheel * 9.81) N

= (50 kg * 9.81) N

= 490.5 N

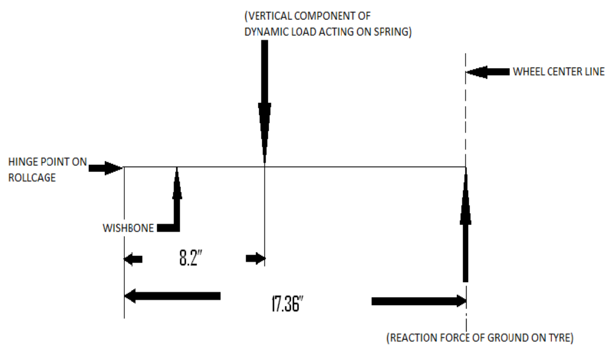

Fig.3. Forces on front wishbone

Considering the wishbone hinges as the point about which moment is taken;

Horizontal distance of reaction force from hinge point

= 17.36” (44.09 cm) ….from suspension geometry

Horizontal distance of strut attachment point from hinge point = 8.2” (20.828 cm)

By taking moment about hinge points :

490.5 * 17.36 = Spring Force * 8.23

∴ Spring Force = 1034.6 N

Considering the dynamic factor,

Dynamic force acting on the spring = 2586.59 N

According to the ride conditions and road quality for an ATV, it is concluded that the optimum spring travel should be approx. 4” (10.16 cm)

Hence, Required Spring Stiffness

$$= \frac{\text{Dynamic Spring Force}}{\text{Spring Deflection}} = \frac{2586.59}{101.6}$$

= 25.46 N /mm

≈25 N/mm

2) *Rear spring*

Angle of inclination of the strut = 80^o (from horizontal)

Point of attachment of strut = 6.5” (16.51 cm) from chassis end …(from suspension geometry)

Reaction force acting from the ground on the wheel

= (Mass per wheel * 9.81) N

= (80 kg * 9.81) N

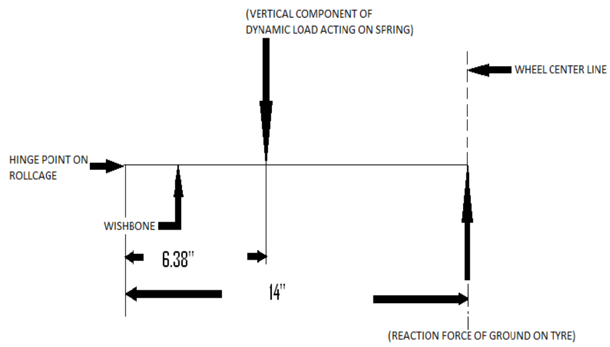

Fig.4. Forces on rear wishbone

Considering the wishbone hinges as the point about which moment is taken;

Horizontal distance of reaction force from hinge point = 14” (35.56 cm) …..(from suspension geometry)

Horizontal distance of strut attachment point from hinge point = 6.38” (16.02 cm)

By taking moment about hinge points :

784.8 * 14 = Spring Force * 6.38

∴ Spring Force = 1722.13 N

Considering the dynamic factor,

Dynamic force acting on the spring = 4305.325 N

According to the ride conditions and road quality for an ATV, it is concluded that the optimum spring travel should be approx. 4” (10.16 cm)

Hence, Required Spring Stiffness

$$= \frac{\text{Dynamic Spring Force}}{\text{Spring Deflection}} = \frac{4305.325}{101.6}$$

= 42.375 N

≈40 N/mm

Table 1. Spring dimensions

Sr. No.	**Parameter**	**Front Suspension**	**Rear Suspension**
	Material	Grade 4 oil hardened spring steel	
1	Wire diameter	11 mm	11 mm
2	Inner coil diameter	55 mm	55 mm
3	Outer coil diameter	66 mm	66 mm
4	Total number of turns	22	14
5	Free length of strut	365 mm	292 mm
6	Pitch of suspension spring	18 mm	27 mm
7	Eye-to-eye length of strut (unloaded)	456 mm	484 mm
8	Stiffness	25 N/mm	40 N/mm
9	Maximum dynamic spring travel	101.12 mm	100.88 mm

B. *Design of wishbones*

The design parameters that govern the dimensions of the wishbone are :

i) Available length for wishbones: 32 inches

ii) Available width for wishbones: 20 inches

1) *Front wishbone*

The front wishbones are standard A-arms and the dimensions are decided on the basis of the length and width constrains (as shown in Fig.5). The wishbones have unequal length.The upper wishbone is shorter than the lower wishbone.The advantage of having different lengths is that when the car takes a turn a negative camber is induced which increases the stability.The unequal lengths also result in a positive camber of 1.5°.The strut is mounted on the lower wishbone and the knuckle is attched to the wishbone by a ball joint. The wishbone is then tested using Autodesk Inventor.

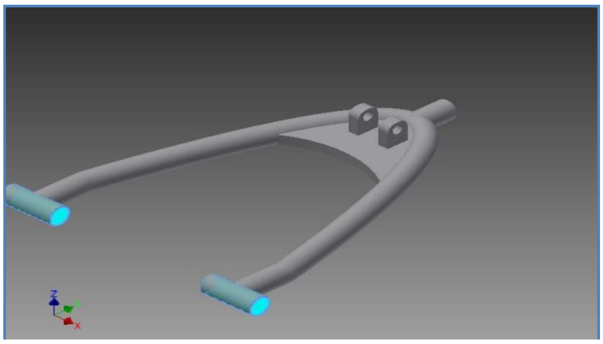

Fig.5.Front Wishbone

2) Rear wishbone

Initially, the A-arm was considered for the rear suspension. However, while the vehicle takes a turn, due to the horizontal forces acting on the attachments of the wishbones and the knuckle and due to lack of steering on the rear wheels, there may be toe-in or toe-out of the wheels. This may lead to improper steering and may result in unbalance. Excess toe-in may cause oversteer while turning leading to loss of control. Excess toe-out may cause understeering while turning.To avoid any toeing, the A-arm is converted into H-arm (as shown in Fig.6). Thus the vertical pin knuckle-wishbone attachment is converted into horizontal pin attachment. This prevents formation of an axis and hence the possibility of toeing of the wheels. This ensures proper alignment and steering. It also increases the ride stability and linear travel.

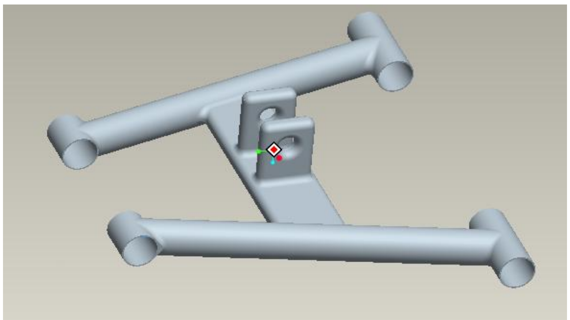

Fig.6.Rear Wishbone

C. *Design of knuckle*

A knuckle is used to connect the wishbones to the wheel hub.

1) *Front knuckle*

The first step in the design was market research. A standard knuckle of MARUTI SUZUKI ESTEEM was selected from the market and studied. The suspension system of the Esteem is MacPherson type, hence the knuckle had to be modified. The designed knuckle is shown. (Fig.7)

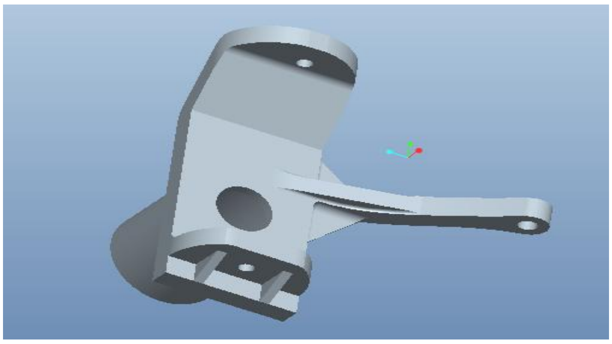

Fig.7.Front Knuckle

Due to lack of funds the above design could not be manufactured.The knuckle of a maruti 800 was modified so that it could accmmodate the designed wishbones.The modified design is shown below.

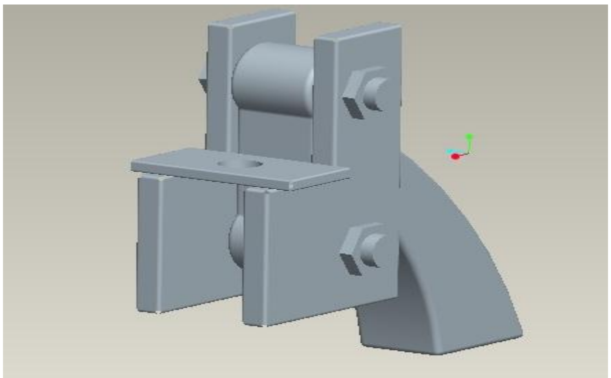

Fig.8.Modified Front Knuckle

2) *Rear knuckle*

The rear knuckle was designed to accommodate the designed H-arms (Fig.9)

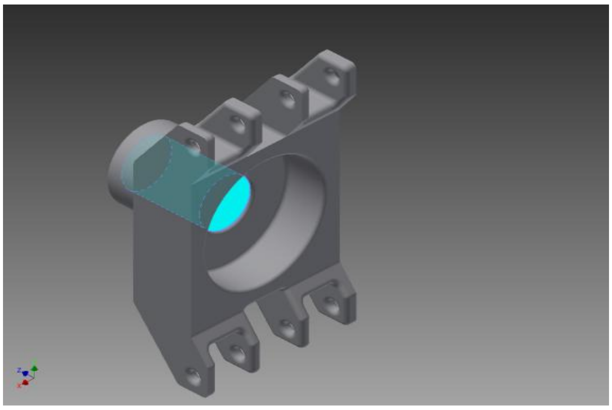

Fig.9.Rear Knuckle

The rear knuckle too could not be manufactured due to lack of funds.the knuckle of an esteem was modified as shown in the figure

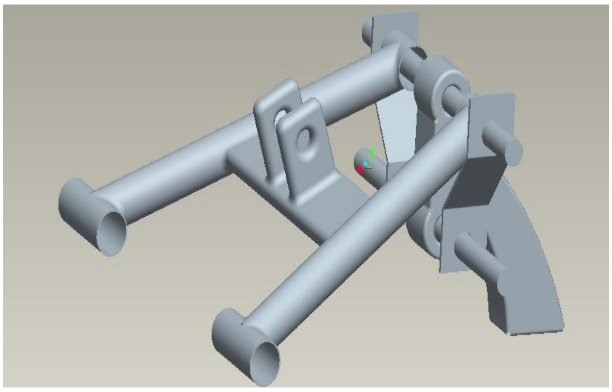

Fig.10.Modified Rear Knuckle

TESTING OF DESIGNED COMPONENTS

Analysis of all the parts was done using Autodesk inventor.

Wishbones

The front lower wishbone was tested as the strut is attached on the lower wishbone due to which most of the load acts on the lower wishbone. The wishbone was tested on Autodesk inventor. The two hinge points and ball joint were considered as fixed points and a load of 2586.59 N(load on spring) was applied at the strut attchment point.

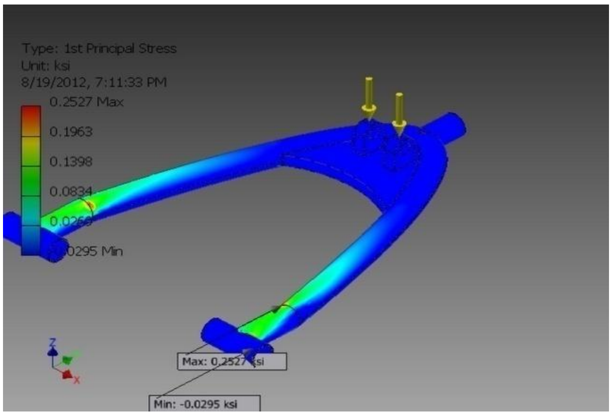

Fig.11.Front Wishbone

Load applied: 2586.59 N

Factor of safety: 1.5

Result: Design is safe

The rear upper wishbone was tested as the strut attachment point was on the upper wishbone. The hinges were considered as fixed points and a load of 4305.325 N was applied at the strut attachment point.

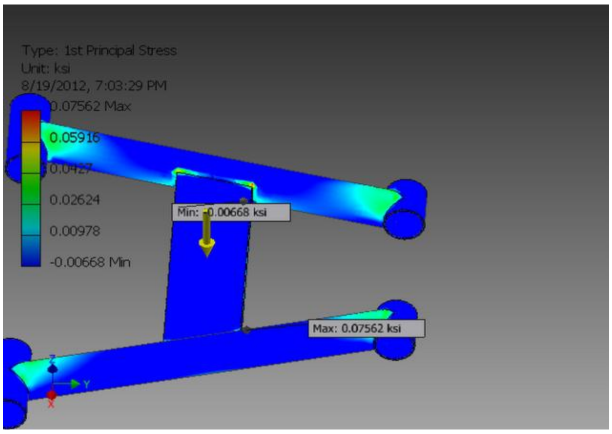

Fig.12.Rear Wishbone

Load applied: 4305.325 N

Factor of safety: 1.5

Result: Design is safe

B. *Knuckles*

The hub end of the knuckle was considered fixed and a load of 2586.95 N was applied at the lower part of the knuckle as shown in fig.13.

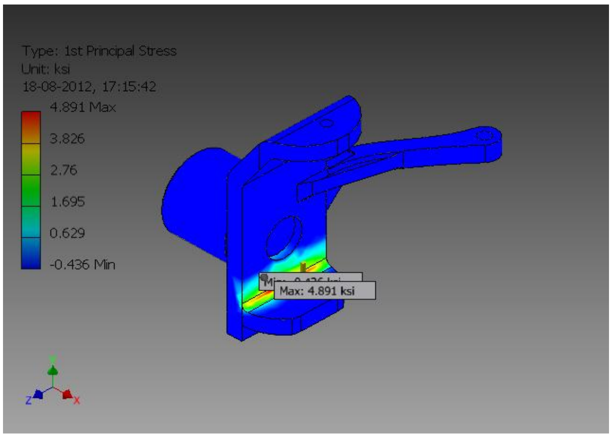

Fig.13.Testing of front knuckle

Load applied: 2586.59 N

Factor of safety = 3.5

Result: Design is safe

The attchment for the front knuckle was tested and the result (Fig 14).

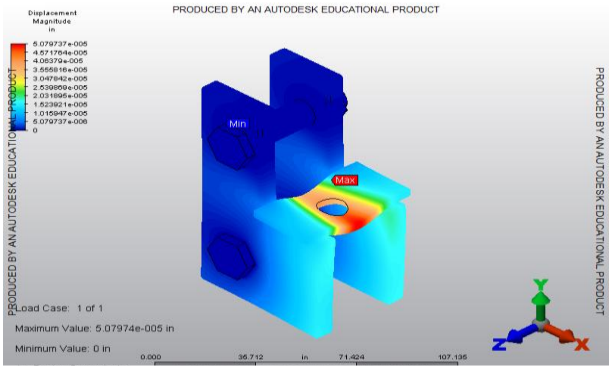

Fig.14.Testing of front knuckle attchment

The rear knuckle was tested in a similar way.the results are shown below

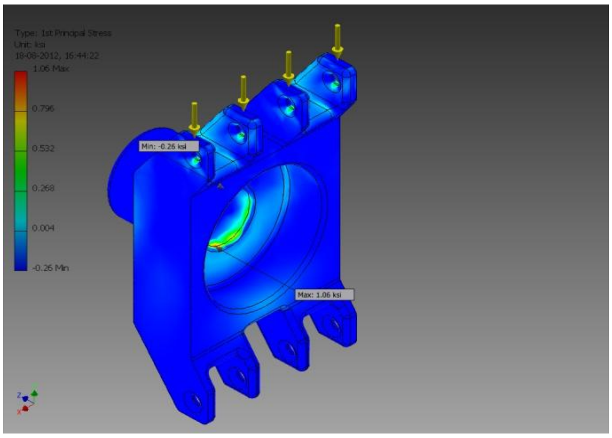

Fig.15.Testing of rear knuckle

Load applied: 4305.325 N

Result: Design is safe (Factor of safety = 4)

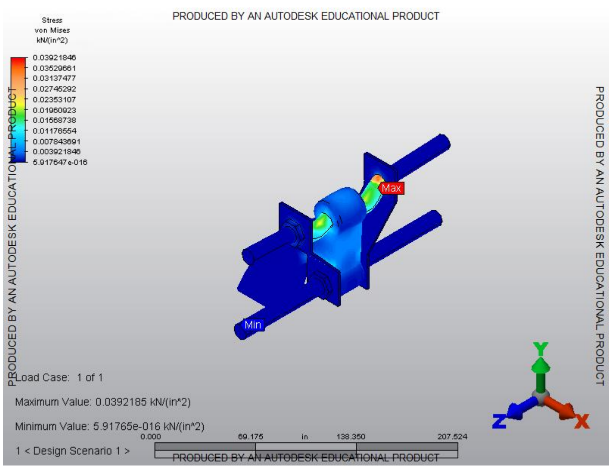

Fig.16 Testing of modified rear knuckle

Load applied: 2586.59 N

Factor of safety = 3.5

Result: Design is safe

IV. FABRICATION

The fabrication of all the parts was done in the workshop.The final fabricated parts are shown below.

Material used for wishbones: AISI 1026

Dimensions of pipe: 19 mm ID, 3 mm thickness

Material used for all other fabrications and modifications:

Mild Steel plates of thickness 4 mm and 8 mm

Fig.17.Fabricated front wishbone

Fig.18.Fabricated rear wishbone

Fig.19 Front knuckle with attachment

Fig.20 Rear Suspension

Fig 20. Final Assembly

V. REFERENCES

[1] Christina Elena Popa, '*Steering System and Suspension System*', University Of South Queensland

[2] Edmund F. Gaffney and Anthony R. Salinas, '*Introduction to Formula SAE Suspension*', University Of Missouri

[3] Mitchell W., 'Force based roll centres and kinematic roll centres', SAE-India

[4] Gertz L., L. Laranja, 'An off-road suspension system', University Of Brazil

[5] Gerrard M., 'Roll centres and jacking forces', Engineering Solutions

[6] NK Giri, *'Automobile Mechanics'*, Khanna Publications, 1996

[7] Kirpal Singh, *'Automobile Engineering'*, Standard Publishers Distributors, 2008

[8] Thomas D.Gillespie, *'Fundamentals of Vehicle Dynamics'*

[9] T.K. Garrett, K. Newton, W. Steeds, *'The Motor Vehicle'*, Butterworth-Heinemann, 2000

[10] Design Data Book, PSG Technology Institute

◈◈◈