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DESIGN, ANALYSIS AND SIMULATION OF DOUBLE WISHBONE SUSPENSION SYSTEM

Asst. Prof. N.Vivekanandan[1], Abhilash Gunaki[2] , Chinmaya Acharya[3], Savio Gilbert[4] and Rushikesh Bodake[5]

[1]Assistant Professor, Pimpri Chinchwad College of Engineering (PCCOE), Pune, India
[2,3,4,5]Student, BE Mechanical, PCCOE, Pune, India

Abstract
The main objective of the paper is to design and analyze the entire double wishbone suspension system for an All Terrain Vehicle for improving the stability and handling of the vehicle. There has been tremendous development in the suspension system. The topic is focused on designing the above mentioned suspension systems considering the dynamics of the vehicle along with minimizing the unsprung mass. The suspension system of an All Terrain Vehicle needs to be durable, light weight, efficient and less expensive. The vehicle must be able to withstand the harsh environment of off-road terrain. Stability of the vehicle and the ride comfort is given a prominent importance in this project.

1. INTRODUCTION
All Terrain Vehicle (ATV) is a vehicle that travels on low pressure tires driven using handlebar or steering wheel for steering control. Although, ATVs were first designed only for a single operator but now-a-days many companies have developed ATVs with two or more seats. In most of the countries around the globe, these vehicles are banned on streets. [1] All Terrain Vehicles is a package of different systems that are designed to enrich the performance and to provide comfort to the driver. Different systems include chassis, steering system, suspension system, braking system and drive train. All these mentioned systems are inter-dependent. Failure of a single system or a part may lead to the death of the operator or driver. ATVs are also popular for their good aesthetics and their sporty look. Suspension system of as All Terrain Vehicle is one of the most critical system that needs to be designed for better stability and comfort for the operator. Suspension system is generally designed in relationship with the steering system. [1]

2. SUSPENSION SYSTEM
Suspension system is referred to the springs, shock absorbers and linkages that connect the vehicle to the wheels and allows relative motion between the wheels and the vehicle body. Suspension system also keeps the driver or operator isolated from bumps, road vibrations, etc. Also, the most important role played by the suspension system is to keep the wheels in contact with the road all the time. Good suspension system and better handling is the characteristic of a good All Terrain Vehicle (ATV). [4]

One of the functions of suspension system is to maintain the wheels in proper steer and camber attitudes to the road surface. It should react to the various forces that act in dynamic condition. These forces include longitudinal (acceleration and braking) forces, lateral forces (cornering forces) and braking and driving torques. It should resist roll of the chassis. It should keep the wheels follow any uneven road by isolating the chassis from the roughness of the road. [4]

All the dynamic parameters are to be considered while designing the suspension system, especially the behavior of the suspension for various loading cases. Besides the dynamic parameters, other factors considered in design process are cost, weight, package space, manufacturability, assembly, etc.

3. TYPES OF SUSPENSION SYSTEM
Generally, the suspension system is classified into two main types- Dependent Suspension System and Independent Suspension System.

3.1 Dependent Suspension System
This type of suspension system acts as a rigid beam such that any movement of one wheel is transmitted to the other wheel. Also, the force is transmitted from one wheel to the other. It is mainly used in rear of many cars and in the front of heavy trucks. Different types of dependent suspension system are [3]

- Leaf Spring Suspension
- Panhard rod
- Watt's Linkage

3.2 Independent Suspension System

This type of suspension allows any wheel to move vertical without affecting the other wheel. These suspensions are mainly used in passenger cars and light trucks as they provide more space for engine and they also have better resistance to steering vibrations. Different types of independent suspension system are [3]

- Swing Axle Suspension
- Macpherson Strut Suspension
- Double Wishbone Suspension
- Trailing Arm Suspension
- Semi-trailing Arm Suspension
- Transverse Leaf Spring Suspension

Out of all the above mentioned independent suspension systems, Double Wishbone Suspension System is the most common type of suspension system used in the passenger cars and most of the All Terrain Vehicles.

4. DOUBLE WISHBONE SUSPENSION SYSTEM

Double Wishbone Suspension System consists of two lateral control arms (upper arm and lower arm) usually of unequal length along with a coil over spring and shock absorber. It is popular as front suspension mostly used in rear wheel drive vehicles. Design of the geometry of double wishbone suspension system along with design of spring plays a very important role in maintaining the stability of the vehicle. [3]

This type of suspension system provides increasing negative camber gain all the way to full jounce travel unlike Macpherson Strut. They also enable easy adjustment of wheel parameter such as camber. Double wishbone suspension system has got superior dynamic characteristics as well as load-handling capabilities. [4]

5. DESIGN OF WISHBONES

Design of wishbones is the preliminary step to design the suspension system. Initially, the material is selected using Pugh's Concept of Optimization. Based on the properties of the selected material, the allowable stress is calculated using sheer stress theory of failure. The roll-centre is determined in order to find the tie-rod length. The designed wishbones are modeled using software and then analyzed using Ansys analysis software to find the maximum stress and maximum deflection in the wishbone.

5.1 Material Selection of Wishbone

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.

Initially, three materials are considered based on their availability in the market- AISI 1018, AISI 1040 and AISI 4130. By using Pugh's concept of optimization, we have chosen AISI 1040 for the wishbones. The main criteria were to have better material strength and lower weight along with optimum cost of the material.

5.1.1Pugh's Concept

This is a method for concept selection using a scoring matrix called the Pugh Matrix. It is implemented by establishing an evaluation team, and setting up a matrix of evaluation criteria versus alternative embodiments. This is the scoring matrix which is a form of prioritization matrix. Usually, the options are scored relative to criteria using a symbolic approach (one symbol for better than, another for neutral, and another for worse than baseline). These get converted into scores and combined in the matrix to yield scores for each option.

5.1.2Comparison of Materials

The properties of the above mentioned materials which were considered for wishbones are as follows,

Table 1: Properties of Materials

Properties	**AISI 1018**	**AISI 1040**	**AISI 4130**
Carbon Content (%)	0.18	0.40	0.30
Tensile Strength (MPa)	440	620	560
Yield Strength (MPa)	370	415	460
Hardness(BHN)	126	201	217
Cost (Rs./metre)	325	425	725

Table 2: Pugh's concept selection chart

Description Criteria	AISI 1018	AISI 1040	AISI 4130
Total Weight	-2	0	+1
Yield Strength	-1	0	+1
Tensile Strength	-2	+2	0
Cost	+1	0	-2
Elongation at break	-2	+1	0
Net Score	**-6**	**+3**	**0**

Hence, AISI 1040 is selected for wishbones because the net score is highest for AISI 1040.

5.2 Stress Calculation

For ductile materials, allowable stress is obtained by the following relationship [5]:

$$\sigma = \frac{S_{yt}}{fs} \qquad (1)$$

Assume factor of safety, *fs* = 1.2 (as AISI 1040 is a ductile material).[6]

$$\sigma = \frac{415}{1.2} \qquad (2)$$

$$\sigma = 345.83\ MPa$$

This is the value of allowable stress value in the wishbones. The designed wishbone is safe when the induced stress is lesser than the allowable stress value. The allowable stress is determined using Ansys analysis software.

5.3 Determination of Roll Centre

Roll Centre in the vehicle is the point about which the vehicle rolls while cornering. There are two types of roll centres- the geometric roll centre and force based roll centre. The roll centre is the notional point at which the cornering forces in the suspension are reacted to the vehicle body. The location of the geometric roll centre is solely dictated by the suspension geometry, and can be found using principles of the instant centre of rotation. [3]

Determination of roll centre plays a very important role in deciding the wishbone lengths, tie rod length and the geometry of wishbones. Roll centre and ICR is determined because it is expected that all the three elements- upper wishbone, lower wishbone and tie rod should follow the same arc of rotation during suspension travel. This also means that all the three elements should be displaced about the same centre point called the ICR. Initially, wishbone lengths are determined based on track width and chassis mounting. These two factors- track width and chassis mounting points are limiting factors for wishbone lengths. Later, the position of the tire and the end points of upper arm and lower arm are located.

The vehicle centre line is drawn. The end points of wishbones are joined together to visualize the actual position of the wishbones in steady condition. When the lines of upper and lower wishbones are extended, they intersect at a certain point known as Instantaneous Centre (ICR). A line is extended from ICR to a point at which tire is in contact with the ground. The point at which this line intersects the vehicle centre line is called the Roll Centre. [3]
Now, extend a line from ICR point to the steering arm. This gives exact tie rod length in order to avoid pulling and pushing of the wheels when in suspension.

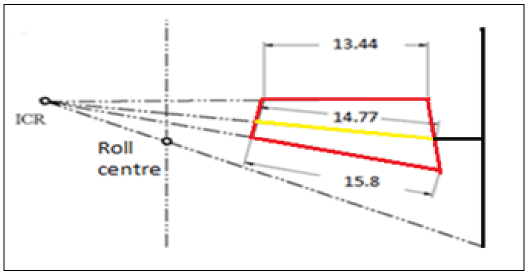

Figure 1 Determination of Roll Centre

6. ANALYSIS OF WISHBONES

Analysis of wishbone in Ansys Analysis Software is necessary in order to determine the induced maximum stress and maximum deflection in wishbones. For analysis, wishbones are first needed to be modelled in software. The modelling of wishbones is done in Pro-E modelling software.

6.1 Pro-E Modelling

Pro-E is modeling software which allows 3D- modeling and 2-D drafting of elements. In order to perform the analysis of wishbone in Ansys, it is necessary to model the wishbones in any of the modeling softwares such as Pro-Engineers, Catia or Solid Works, etc. We have selected to use Pro-Engineers (Pro-E) modeling software because of its availability.

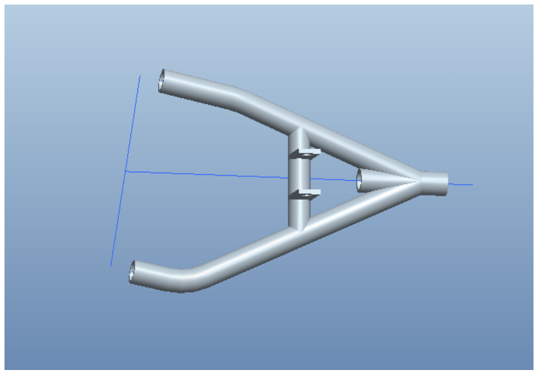

Figure 2 Pro-E model of lower wishbone

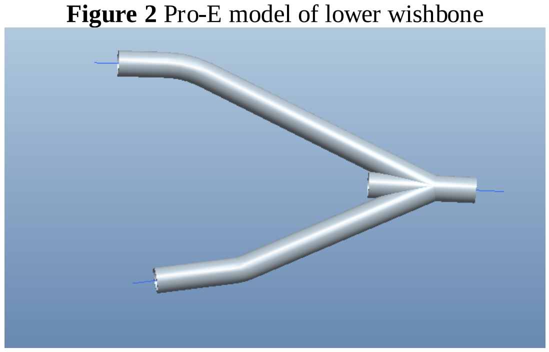

Figure 3 Pro-E model of upper wishbone

6.2 Analysis in Ansys

Ansys is engineering simulation software (computer-aided engineering). Various types of analysis like structural analysis, thermal analysis, etc are possible using Ansys analysis software. In structural analysis in Ansys, boundary conditions are to be defined in order to determine the stress and deflection.

After modelling the wishbones in Pro-E modelling software, these models were imported into Ansys Analysis Software. Various boundary conditions and load cases were applied for determining the maximum stress and maximum deflection for wishbone.

Input parameters are as follows,

Table 3: Wishbone Analysis Input Parameters

Material	AISI 1040
Vertical Load	9600 N
Spring Force	1500 N

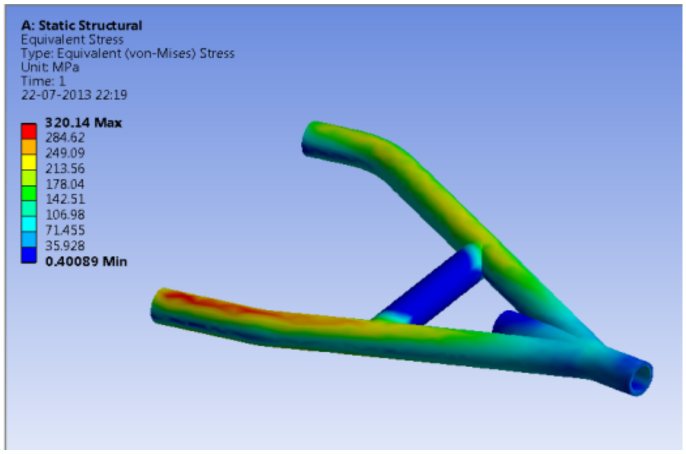

Figure 4 Analysis of lower wishbone in Ansys

6.3 Results of Analysis of Wishbones

Table 4: Results of Analysis of lower wishbone in Ansys

Parameters	Values
Maximum Stress	320.14 MPa
Maximum Deflection	6.013 mm
Allowable Stress	345.83 MPa

Since, Maximum stress induced in wishbone is less compared to allowable stress, hence the wishbone is safe.

7. DESIGN OF SPRING

A spring is an elastic object used to store mechanical energy. Springs are usually made out of spring steel. When a spring is compressed or stretched, the force it exerts is proportional to its change in length. The rate or spring constant of a spring is the change in the force it exerts, divided by the change in deflection of the spring. [5]

Spring is used in order to absorb shocks and for providing springing action for better comfort of the passenger.

7.1 Design Considerations in Spring Design

- Sprung mass= 240 kg
- Unsprung mass= 80 kg
- Wheel displacement= 228mm (9")
- Motion ratio= 0.46

7.2 Specifications of Spring

Table 5: Spring Specifications

PARAMETERS	VALUES
Motion Ratio	0.46
Spring Displacement	105.156
Spring Rate	14.26 N/mm
Wheel Rate	67.39 N/mm
Wire Diameter	8 mm
Coil Mean Diameter	64 mm
Number of coils	11 active + 2 inactive
Solid length	104 mm
Free length	245.15 M

7.3 Analysis of Spring

Spring is analyzed in Ansys analysis software so as to determine the actual maximum deflection of spring corresponding to the maximum spring force. Also, the maximum stress value corresponding to the maximum spring force is determined.

In spring analysis, one end of spring is fixed and vertical load has been applied on the other side.

Table 6: Spring Analysis Results

Parameters	Value
Maximum Force	1500 N
Maximum Deflection	106 mm
Maximum Stress	967.32 MPa

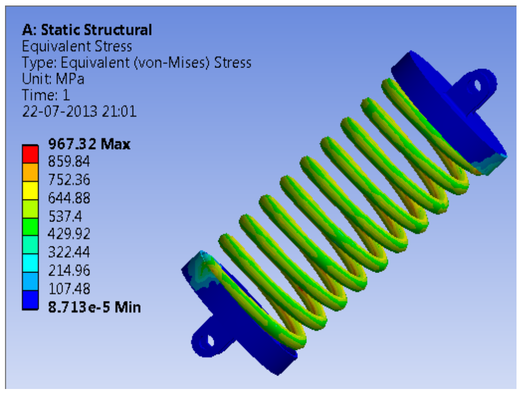

Figure 5: Analysis of Spring in Ansys

8. SIMULATION OF SUSPENSION SYSTEM

Lotus Engineering Software has been developed by automotive engineers, using them on many powertrain and vehicle projects at Lotus over the past 15 years. It offers simulation tools which enable the user to generate models very quickly, using a mixture of embedded design criteria and well-structured interface functionality.

8.1 Suspension Geometry in Lotus

Lotus simulation software has been used to simulate the suspension geometry of double wishbone suspension system. Various co-ordinates of the entire system are given as input and the virtual model is built. It looks like as shown:

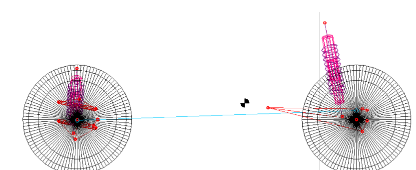

Figure 6: Suspension Geometry in Lotus

8.2 Camber Change in Bump

Camber change in bump has been simulated using Lotus simulation software. The camber change in bump looks like as shown:

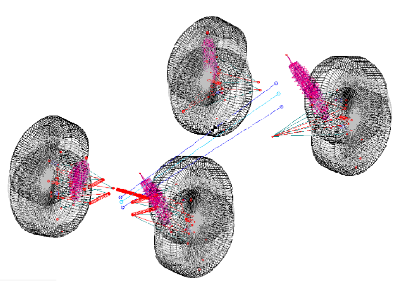

Figure 7: Camber Change in Bump

8.3 Plot of Camber Angle Vs Roll Angle

From the below graph of Camber Angle vs. Roll Angle, it is clear that, as the camber of the tire varies in bump and droop then roll angle also varies. The camber angle varies from -2^0 to +2^0 with roll angle.

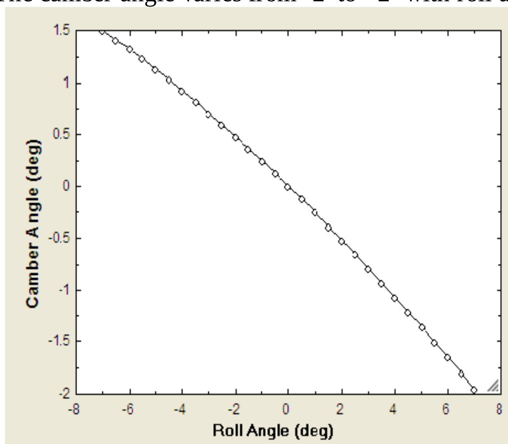

Figure 8: Camber Angle vs Roll Angle

9. CONCLUSION AND FUTURE WORK

We have designed the double wishbone suspension system and then simulated it in the LOTUS software. This was followed by analysis of the system in the ANSYS. The stipulated objectives namely providing greater suspension travel, reducing the unsprung mass of the vehicle, maximizing the performance of the suspension system of the vehicle and better handling of vehicle while cornering; have been achieved.

The suspension system can be further modified for decreasing the weight and cost. Transverse leaf spring can be used to decrease the weight of the suspension assembly. Pneumatic suspensions can be incorporated in the future for better performance.

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