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Sikka, Piyush
Department of Mechanical and Automation Engineering, Maharaja Agrasen Institute of Technology

Arora, Rishabh
Department of Mechanical and Automation Engineering, Maharaja Agrasen Institute of Technology

Singh, Prabhsharan
Department of Mechanical and Automation Engineering, Maharaja Agrasen Institute of Technology

Behl, Monsoon
Department of Mechanical and Automation Engineering, Maharaja Agrasen Institute of Technology

他

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Suspension and Steering Setup for a 4-wheel All-terrain Vehicle

Piyush Sikka[1], Rishabh Arora[1], Prabhsharan Singh[1], Monsoon Behl[1], Rakesh Chander Saini[1], Ramakant Rana[1*]

[1]Department of Mechanical and Automation Engineering, Maharaja Agrasen Institute of Technology, Delhi 110086, India

*Author to whom correspondence should be addressed:
E-mail: 7ramakant@gmail.com

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Abstract: Suspension and steering are subsystems to any automobile which determine how the vehicle dynamically behaves with driver's and terrain's combines input and output as response of the vehicle deciding direction, stability and ride, roll characteristics which were used in this study to obtain optimum lap times. The roll cage acts as a skeleton to the body and the suspension system as the limbs trying to maintain stability and safety in the cockpit. This study is based on BAJA SAE rulebook constraints. An iterative process is adopted to finalize suspension parameters followed by ride and roll calculations and suspension geometry selection. The entire setup is simulated using lotus shark suspension analysis and MSC Adams car multibody dynamics suspension testing in various simulations and loading conditions. The change in suspension parameters such as camber gain, castor, wheelbase and toe change during different conditions were noted as design decision parameters and the geometry was optimized accordingly. The subsystem component design such as control arms and mountings were designed using CAD and simulated using FEA modelling on ANSYS simulation software. The resulting structural deformation and dynamic stability were chosen as design decision parameters. The manufacturing process was aided by use of jigs and fixtures to eliminate errors.

Keywords: ATV; Design; Suspension; Steering System

1. Introduction

An ATV or an All-Terrain-Vehicle as the name implies, is a vehicle which is designed to drive over a wide variety of terrains, due to optimum suspension design and utilization of its Roll cage aided by data driven fine tuning of vehicle dynamics characteristics. As the design is custom made for off-roading, the loads in this case is higher as compared to even terrain vehicles, which may try to change the structural integrity and characteristics of the vehicle (Roll Cage & suspension system), to which all the sub -assemblies is attached[1,2]. This, making it a necessity for an ATV, to sustain such anomalies, which come through designing and simulating our vehicle to overcome these static and dynamic loads[3,4].

The objective of this paper is to properly concur upon the suspension parameters which provide stability to the vehicle to an extent which decreases the load on the Roll Cage significantly whilst providing higher maneuverability[5,6]. Though there are many parameters which will affect the performance of an ATV, the scope of this study will be limited towards design and analysis of the suspension geometry[7,8].Their integration to the Roll Cage for the best results as shown in figure 1.

Fig.1: Isometric view of BAJA suspension components

2. Selection of Parameters

In Student formula or M-Baja competitions, the key role of designers is selection of suspension parameters as they are directly responsible for the dynamic performance of the vehicle. Providing maximum traction regain, driver control and agile maneuvering characteristics were the major objectives while parametric selection of a 4-wheel drive BAJA vehicle.

As Baja vehicles are designed and manufactured under a certain set of rules prescribed by SAE, Track width is constrained at 64 inches and wheelbase at 108 inches[9-12]. A typical trackwidth to wheelbase ratio is kept around 0.8 for off-terrain vehicles ensuring that it doesn't tend to 1 because of increased moment of inertia resulting in roll-over[12-16].

To acquire oversteer characteristics i.e., creating a condition that the vehicle turns by a shorter radius than provided by the steering wheel (driver) under neutral steer conditions[17,18]. It is advisable to keep track width of rear to be shorter than front[19,20]. The reason for the same is increased rotational moment resistance generated also known as roll-stiffness which is directly affected by the trackwidth, hence promoting the oversteer condition[21,22].

Now, after selecting these parameters on the basis of experience and theory, further suspension parameters were set on the basis of experience and iterative methods[23]. The iterative methods involve changing one parameter and checking all dynamic performance of the vehicle on a particular track and keeping all other characters the same[23,24]. These methods usually take years of iterations to generate a stable and optimized suspension design[25,26]. For instance, we can iterate our suspension design by changing Castor Angle in front, anti-dive or anti-squat angles, different Track Width combinations of front and rear, Kingpin angles, and various steering angle combinations[27,28].

As per experience and in Baja Vehicles usually castor angle is set around 5-13 degree depending on other characteristics[29]. Higher caster angle increases high speed cornering stability but also increases steering effort, hence, all parameters affect other characteristics simultaneously[30,31]. Hence a set of all parameters should balance to increase stability[32].

Table 1: Suspension Parameters

S.No.	Parameters	Generic Values
1	Castor Angle	5-13 degrees
2	Kingpin Angle	5-10 degrees
3	Ground Clearance	12-15 inches
4	CG Height	20-25 inches
5	Roll Centre	200-300 mm
6	Wheel Travel	8-10 inches

Following is a generic set of parameters chosen for off-roading vehicles in Table 1.

Centre of gravity and ground clearance of the vehicle are two of the most important parameters in vehicle dynamics[33]. Centre of Gravity of the vehicle is considered for the kerb weight only for dynamics. CG of a vehicle has an effect on Rolling and pitching characteristics[34]. So, CG must be optimum to eliminate excess Roll and pitch which increases instability[35]. Ground Clearance for Baja vehicles should be kept as per SAE rules prescribed in Rulebook[36]. Generally, it is kept between 12-14 inches.

3. Geometry Selection

After finalizing the characteristics and parameters, geometry selection is the next step. For baja Vehicles independent suspension setups are preferred. Wishbone geometry is being used by a variety of baja Vehicles[37]. Its Compactness, lightweight and easy assembly are key features to choose this suspension geometry for front[38]. H-Arm Suspension Geometry and Semi-Trailing are generally used in rear of baja vehicles. H-arm suspension is used for its sturdiness and simple design. Semi-trailing on the other hand is compact, and lightweight. Many new vehicles are now switching to semi trailing because of its compact design[30]. Teams should choose geometries on the basis of their past experiences and upcoming objectives for the new vehicle design. Front suspension design is shown below in figure 2 below.

Fig.1: Front view of suspension links assembly of an BAJA ATV

4. Lotus Suspension Design

After finalizing all the parameters and geometry for front and rear, Lotus suspension software is used to design suspension as shown in figure 3. Roll center, track width wheelbase and vehicle integrity are key factors considered[28]. Toe Angle deflection against wheel travel is kept to minimum to avoid bump steer and increase dynamic stability. Steering angles iteration can be done after suspension design according to the steering geometry chosen[29]. Ackerman Percentage is calculated by generic formulas using inner and outer steering angles.

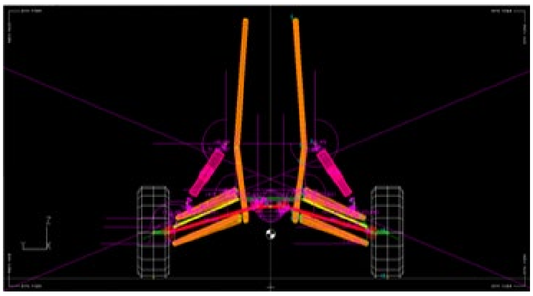

Fig.2: Suspension Geometry on LOTUS

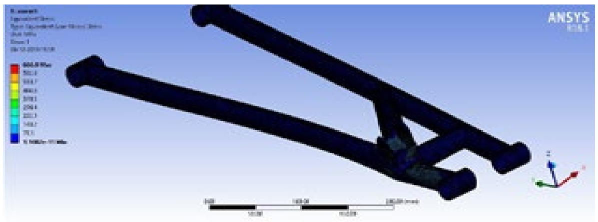

Fig.3: Analysis of H- arms

Fig.4: Meshing and modeling of upper A-arm

5. Ride Calculations

Ride rate, spring rate and and other ride parameters can be calculated using the following formulas and the method is described in the book “RCVD-Milliken”

$$Spring\ Rate = Ksf = MSf/2 * 9.8 * (Shock\ rebound) * 25.4 * sin\theta \quad (1)$$

$$\boldsymbol{Wheel\ Rate = Kwf = Ksf * (MR)2} \quad (2)$$

$$\boldsymbol{Front\ Ride\ Frequency = \omega ns} \quad (3)$$

$$\boldsymbol{= 12\pi\ (Kwf/\ MSf/2)1/2}$$

$$\boldsymbol{Rear\ Ride\ Frequency = \omega ns} \quad (4)$$

$$\boldsymbol{= 12\pi\ (Kwr/\ MSr/2)1/2}$$

6. Force Calculations

Forces on various suspension components are calculated using Lotus and Force on complete vehicles considering kerb weight is calculated by conservation of momentum equation and force momentum equation. Collision time is considered to be 0.2 sec.

For Instance,

Front impact

- Velocity = 50kmph - 13.5 m/s
- Final velocity = 0
- Momentum change= 210(13.5-0) =2835
- Force =2835/0.17 = 16676N
- Force Applied 17000N
- 440 Mpa

Similarly different load cases were generated and forces were calculated. After force calculation, now comes the CAD design and CAE part.

7. Modeling and Meshing

CAD models of the components are designed using parametric modelling techniques on SolidWorks followed by CAE analysis where boundary conditions are applied and analysis were performed in a phased manner.

The worst-case scenario for analysis was taken in full bump or droop condition for car analysis. Results are shown in Figure 4 and 5.

8. Multi-Body Dynamics

After finalizing the suspension geometry on Lotus Software. The whole car model was generated using custom templates in ADAMS CAR software in which all parameters were iterated and simulated for estimating vehicle dynamics next to real-time dynamic situations. Vehicles were made to run to virtual tracks to test the reliability of vehicle.

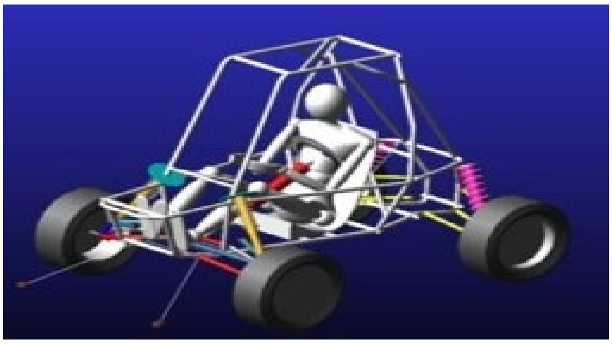

Fig.5: MBD on ADAMS

From the simulation, various parameters were recorded against wheel travel - Dynamic Caster, Dynamic Camber, Dynamic Toe, Kingpin angle Change, Ackerman angle change, Anti Dive change, and anti-squat change. Some of the results are shown in figure 7,8,9,10,11.

Fig.6: Dynamic Caster Angle Vs Wheel Travel

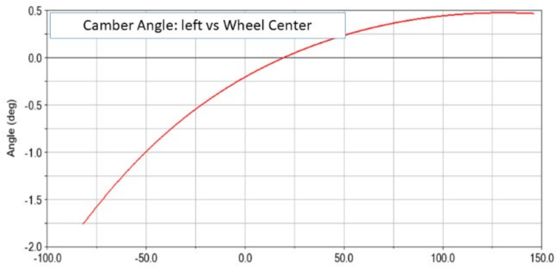

Fig.7: Dynamic Camber Angle Vs Wheel Travel

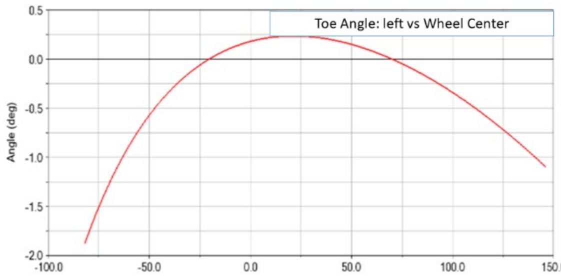

Fig.8: Dynamic Toe Angle Vs Wheel Travel

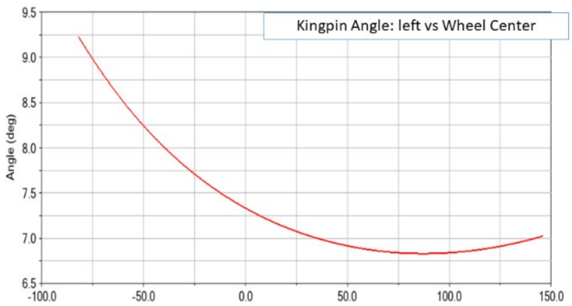

Fig.9: Kingpin Angle Vs Wheel Travel

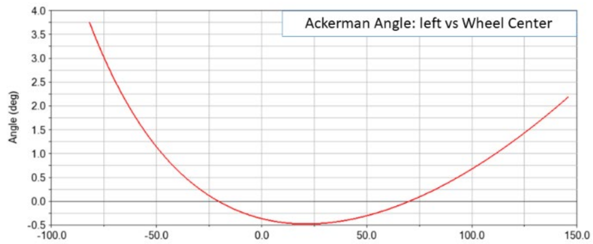

Fig.10: Ackerman Angle Vs Wheel Travel

9. Fixture for Manufacturing

To manufacture the arms accurately and precisely. This fixture was used to reduce the welding contraction error and human errors. One of the key features of the fixture was the proper orientation of Arms and the correct position of suspension points in space making it independent from chassis error. This not only helps to save time but also helps in replicating arms accurately.

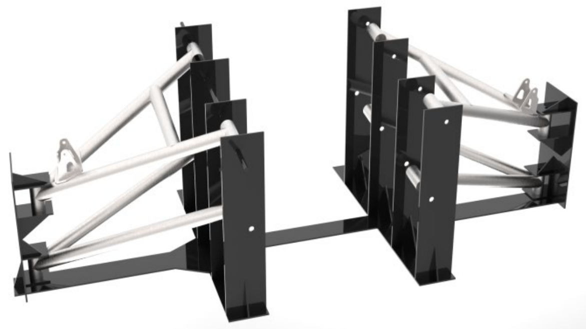

Fig.11: Jig Setup for Arms

Fig.12: Arms and Chassis Setup

10. Conclusion

This paper provides descriptive information about all the necessary equipment and the data which would be needed to ensure the proper optimization of chassis and the suspension and their integration of an All-terrain-Vehicle. The primary objective of this paper was to design and procure the perfect conditions, analyze constraints and showcase the affecting parameters.

The usage of jigs to get a perfect layout for the arms, minimizing the manufacturing defects or to use real-time dynamic simulation using ADAMS car, to get those perfect load conditions to incorporate and adjust the parameters to the optimum which eventually helped us to overcome theoretical difficulties and increase our understanding towards vehicle design.

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