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Research Article

Design and Analysis of an ATV Suspension System

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Abstract

An All Terrain Vehicle (ATV), as the name implies is a vehicle designed to handle a wider variety of terrain than most other vehicles. Over the period ATVs have been used for performing number of applications ranging from military to desert and jungle safaris. The efficacy of an ATV is determined on the basis of its ability to sustain the irregularities of the terrain with ease. The system that implements the vital role of damping such undesired commotion and vibrations is the suspension system. The suspension systems are mainly classified as dependent suspensions and independent suspensions. A dependent suspension normally has a beam or live axle that holds wheels parallel to each other and perpendicular to the axle. When the camber of one wheel changes, the camber of the opposite wheel changes in the same way. An independent suspension allows wheels to rise and fall on their own without affecting the opposite wheel. The front suspension and rear suspension of a vehicle can be different as per the application requirements. The paper focuses on the designing, analysis and simulation of an ATV suspension system which was designed for a national level event namely BAJA SAEINDIA.

Keywords: *Wishbones, Trailing arms, Camber angle, Toe angle, Anti-dive, Structural analysis*

Introduction

Automobiles were initially developed as self-propelled versions of animal drawn vehicles. However animal drawn vehicles had been designed for relatively slow speeds and lacked a suspension system that could withstand the higher speeds permitted by internal combustion engines. The suspension of modern vehicles need to satisfy a number of requirements whose aims partly conflict because of different operating conditions such as loaded/ unloaded, acceleration/ braking, constant/ variable terrain road, straight running/ cornering. For the purpose of ensuring the optimum handling characteristics of the vehicle in a steady state as well as in a transient state, the wheels must be in a defined position with respect to the road surface for the purpose of generating the necessary lateral forces. The build-up and size of the lateral wheel forces are determined by specific toe and camber changes of the wheels depending on the jounce and movement of the body as a result of the axle kinematics(roll steer) and operative forces(compliance steer). This makes it possible for specific operating conditions such as load and traction to be taken into consideration. By establishing the relevant geometry and kinematics of the axle, it is also possible to prevent the undesirable diving or lifting of the body during braking or accelerating and to ensure that the vehicle does not exhibit any tendency to over-steer and displays predictable transition behaviour for the driver.

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1. Suspension Parameters

1.1. Undamped System: Undamped systems are those in which there are no forces opposing the vibratory motion to dissipate energy.

1.2. Damped System: Damped systems are those in which energy is dissipated by forces opposing the vibratory motion.

1.3. Damping Ratio: Damping ratio is the ratio of the amount of viscous damping present in a system to that required for critical damping. Where comfort takes priority over performance, leading to low damping ratios, and minimum pitching over bumps. Racecars in general run higher damping ratios, and have a much smaller concern for comfort, leading to some racecars using higher front ride frequencies. The higher damping ratios will reduce the amount of oscillation resultant from road bumps, in return reducing the need for a flat ride.

1.4. Sprung weight and un-sprung weight: All weight which is supported by the suspension, including portions of the weight of the suspension members are regarded as sprung weight. Un-sprung weight includes the suspension upright and all components attached to it; the brake caliper, brake disc, wheel, tire and a portion of suspension arms. Sprung weight is protected from the shocks and vibrations that the wheels experience as they travel over every bump and pothole. This makes for a more comfortable ride and protects the sprung components from destructive and life-shortening shocks and vibrations. Conversely, un-sprung weight must be designed to be tough enough to survive the constant shocks and vibrations, which can be difficult for complex parts such as wireless pressure sensors. In general, it's best to have a high ratio of sprung to un-sprung weight. A higher proportion of sprung weight can then push down on the wheels and tires with more force, keeping them in contact with the pavement or whatever surface they are traveling across. Maintaining contact with the roadway improves handling and traction, and this becomes more of an issue for off-roading and traveling over rough roads. So as a rule, designers try to minimize un-sprung weight to improve handling and steering.

1.5. Spring Rate: The change of load on a spring per unit deflection is spring rate. To minimize the pitching motion of vehicle, the equivalent spring rate and the natural frequency of the front end should be slightly less than those of the rear end. This ensures that both ends of the vehicle will move in phase within a short time after the front end is excited.

1.6. Camber Angle: Camber is the angle of the wheel relative to vertical line to the road, as viewed from the front or the rear of the car. If the top of the wheel is farther out than the bottom (that is, away from the axle), it is called positive camber; if the bottom of the wheel is farther out than the top, it is called negative camber. The cornering force that a tire can develop is highly dependent on its angle relative to the road surface, and so wheel camber has a major effect on the road holding of a car. A tire develops its maximum lateral force at a small camber angle. This fact is due to the contribution of camber thrust, which is an additional lateral force generated by elastic deformation as the tread rubber pulls through the tire/road interface.

1.7. Caster Angle: It is the Forward or rearward inclination of the steering axis.

1.7.1. Positive Caster: Positive caster is when the steering axis is in front of the vertical. The purpose of this is to provide a degree of self-centering for steering the wheel casters around, so as to trail behind the axis of steering. This makes a car easier to drive and improves its directional stability (reducing its tendency to wander). Excessive caster angle will make the steering heavier and less responsive, although, in racing, large caster angles are used to improve camber gain in cornering. Power steering is usually necessary to overcome the jacking effect from the high caster angle.

1.7.2. Negative Caster: Negative caster is when the steering axis is behind the vertical. This is generally only found on older vehicles due to tire technology, chassis dynamics, and other reasons. Modern vehicles do not use negative caster. It will lighten the steering effort but also increases the tendency for the car to wander down the road.

1.8. Toe Angle: When a pair of wheels is set so that their leading edges are pointed slightly towards each other, the wheel pair is said to have toe-in. If the leading edges point away from each other, the pair is said to have toe-out. The amount of toe can be expressed in degrees as the angle to which the wheels are out of parallel, or more commonly, as the difference between the track widths as measured at the leading and trailing edges of the tires or wheels. Toe settings affect three major areas of performance: tire wear, straight-line stability and corner entry handling characteristics.

1.9. Jounce(Bump): Jounce is the upward movement or compression of suspension components. During bump, the dampers and springs absorb the upward movement from cornering or road irregularities (the springs store some of the energy), the dampers then goes into rebound. If there isn't enough damping then the cycle begins again until the car returns to the original ride height, with a bouncing motion to the car. Another trait of under damping is that loads go into tire and suspension relatively slowly, this combined with the bouncing effect means a constant varying downward force on tires. It is important to have enough bump stiffness to be able to deal with uneven surfaces. If there is too much damping, then it is effectively like running no suspension and any upward motion will be transmitted directly to the chassis. Over damping will result in an increase in the loads acting on the suspension and the tires. The handling will feel very harsh and hard, this will affect street driving in terms of comfort levels, this might not be desired for a daily driver. It is undesirable in both under and over damping settings, as it will reduce the handling of the car and will affect acceleration, braking and cornering loads.

1.10. Rebound (Droop): Rebound is the downward movement or extension of suspension components. During rebound (following the bump compression phase) the dampers extend back to their original positions, using up the stored energy from the springs. The rebound stiffness needs to be set at a higher value than the bump setting as the stored energy is being released. If there is no effect of damping on the rebound, the wheel will quickly return through the static level and start to bump again, with the bouncing effect unsettling the suspension with little control. If there is too much rebound stiffness, then the wheel could hold longer in the wheel arch than needed, effectively losing contact with the road as the force to push the wheel back down is slower to respond to the changing surface levels. This state is again far from ideal and it is best to make sure a good level is set for optimal tire contact with road.

1.11. Suspension Roll: The rotation of the vehicle sprung mass about the x-axis with respect to a transverse axis joining a pair of wheel centers.

1.12. Suspension Roll Gradient: The rate of change in the suspension roll angle with respect to change in steady-state lateral acceleration on a level road at a given time and test conditions. The main factors affecting suspension roll gradient are instantaneous center and tire data for inclination angles.

1.13. Roll Camber: The change in camber of the wheels due to relative motion of sprung mass with respect to un-sprung mass is called as roll camber. It is the result of suspension roll. The basic wishbone is such as to give about 50% compensation of roll camber by the basic geometry and 50% by the action of the extra links, so that camber change is optimum.

1.14. Roll Center and Roll axis: The roll axis is the instantaneous line about which the body of a vehicle rolls. Roll axis is found by connecting the roll center of the front and rear suspensions of the vehicle. Assume we cut a vehicle laterally to disconnect the front and rear half of the vehicle. Then, the roll center of the front or rear suspension is the instantaneous center of rotation of the body with respect to the ground.

1.15. 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. A motion ratio close to one is desired in vehicle for better ride and comfort. One should know the desired wheel travel of the vehicle before calculating motion ratio which depends much on the type of track the vehicle will run upon.

1.16. Wheel travel: Wheel travel is the distance that is designed for the wheel/tire assembly to move vertically without bottoming out either at the top or the bottom of the motion. The suspension's job is to ensure that despite any bumps or droops, the vehicle stays as leveled and smooth as possible. While wheel travel is measured on both independent and solid axle suspensions, it is mostly referred to with independent suspension where the vertical travel of each wheel/tire assembly is separate from any of the others, and therefore best able to provide that smooth ride and safe driving experience.

1.17. Anti-dive: Anti-dive is a suspension parameter that affects the amount of suspension deflection when the brakes are applied. When a car is decelerating due to braking there is a load transfer off the rear wheels and onto the front wheels proportional to the center of gravity height, the deceleration rate and inversely proportional to the wheelbase. If there is no anti-dive present, the vehicle suspension will deflect purely as a function of the wheel rate. This means only the spring rate is controlling this motion. As anti-dive is added, a portion of the load transfer is resisted by the suspension arms. The spring and the suspension arms are sharing the load in some proportion. If a point is reached called “100-percent anti-dive”, all of the load transfer is resisted by the suspension arms and none is carried through the springs. When this happens there is no suspension deflection due to braking and no visible brake dive. There is still load transfer onto the wheels, but the chassis does not pitch nose down. The method to achieve anti-dive is controlled by upper and lower control arm pivot points on chassis.

Just like anti-dive in the front suspension, there can be anti-lift in the rear suspension that reduces rebound travel under braking. There is also anti-squat in the rear suspension under acceleration for rear-wheel-drive cars.

2. Design

The design phase involves variety of fronts leading to one absolute design. Firstly, It involves determination of desired system characteristics. Lotus Engineering Suspension Analysis software was used to design and analyse the vehicle suspension hard points to achieve the required suspension characteristics. The Computer Aided Designing (CAD) was done using CATIA V5R21 with design for manufacturing and assembly considerations. Then using ANSYS 15.0 we performed structural analysis of suspension systems in order to assure the flawless performance of our design.

2.1. Design Targets

2.1.1. To isolate high amplitude obstacles by increasing travel.

2.1.2. To maintain the undamped natural frequency from 1.2Hz- 1.5Hz.

2.1.3. To implement anti-dive geometry.

2.1.4. To minimize the chassis roll by maintaining the roll gradient in the range of 1.5^0-2^0/g.

2.2. Lotus Suspension Analysis(LSA): LSA is a design and analysis tool that can be used for both the initial layout of a vehicle and suspension hard points. Models are created and modified through a 3d-viewing environment. This allows hard points to be ‘dragged’ on screen and graphical/numerical results updated in ‘real time’. A template-based approach to the modelling allows users to create their own suspension models, supplementing the ‘standard’ suspension templates provided. Any number of results can be displayed graphically, (e.g. Camber angle, Toe angle), against bump motion, roll motion or steering motion. These results are updated in ‘real time’ as the suspension hard points are moved.

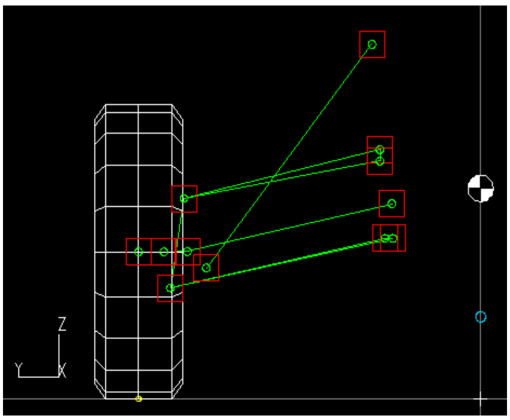

Fig.1 Front suspension hard points

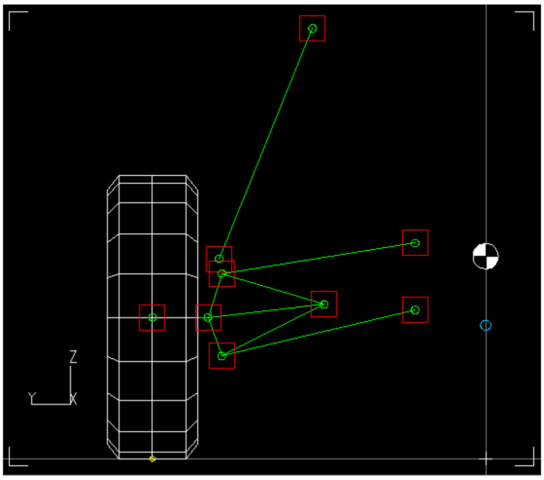

Fig.2 Rear suspension hard points

2.3. Front Suspension: We selected Short Long Arm (SLA) type wishbone front suspension. This suspension system consists of upper and lower wishbones. Both the wishbones were designed in A-arm shape with its narrow end joining the knuckle with ball joints and the wishbone was connected to the chassis at two pivots with heim joints. The suspension system was designed in such a way that the tires remain oriented properly in all modes of motion. This design provided an optimized wheel control and maximum camber gain during cornering. The system is equipped with FOX progressive air shocks which gives us a better performance due to its variable stiffness. The system allows adjusting the geometry of the arms and their mounting locations for fine tuning of performance characteristics.

Table.1 Front suspension parameters

Parameter	Value
Wheel Travel	6 inch(Bump), 4 inch(Droop)
Camber	-1.6^0 (Bump), -0.2^0 (Droop)
Toe	1.29^0 (Bump), 0.7^0 (Droop)
Static Ride Height	12 inch
Motion Ratio	0.608
Natural Frequency	1.30 Hz

2.4. Rear Suspension: The Trailing Arms (TA) were opted for rear suspension system. The system consisted of trailing arm along with camber links. The trailing arm had one end attached to the chassis with heim joint and other end attached at knuckle with pivot system using nuts and bolts. The camber links provide the ability to control the undesired camber change by restricting the lateral motion of the upper and lower ends of the wheels. The two camber links are connected one at the lower end of the TA and other at the upper end of the TA, also the respective opposite ends are joined to the chassis. Camber link is joined at each end with heim joints. The trailing arms design provides better wheel travel and has the advantages of being durable, strong and easy to design for a desired amount of travel and static camber.

Table.2 Rear suspension parameters

Parameter	Value
Wheel Travel	7 inch(Bump), 4.4 inch(Droop)
Camber	-5^0(Bump), -4.5^0(Droop)
Toe	1.2^0(Bump), -1.6^0(Droop)
Static Ride Height	10.5 inch
Motion Ratio	0.709
Natural Frequency	1.38 Hz

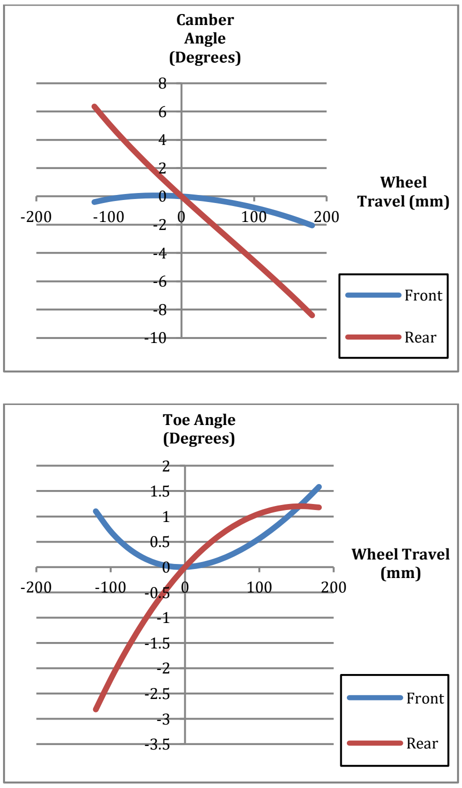

Fig.3 Graphical representation of camber angle and toe angle variation over the wheel travel of front and rear suspension systems respectively from Lotus Suspension Analysis

3. Finite Element Analysis

Finite Element Analysis (FEA) is a computerized method for predicting how a product reacts to real world forces, vibrations, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

EA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes. Mathematical equations help predict the behavior of each element. A computer then adds up all the individual behaviors to predict the behavior of the actual object.

In order to validate the quality of our design we performed finite element analysis with the help of ANSYS workbench 15.0. In the results that we obtained, the yield stresses were below the ultimate stresses under worst case circumstances. Thus assuring the caliber of our design.

The structural analysis of the wishbones and the trailing arms were carried out by considering 3g forces and air shocks bottomed out.

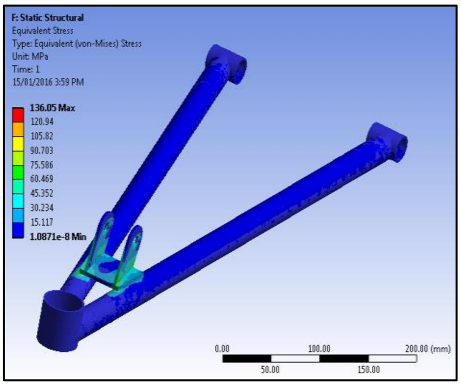

Fig.4 Structural analysis of wishbones

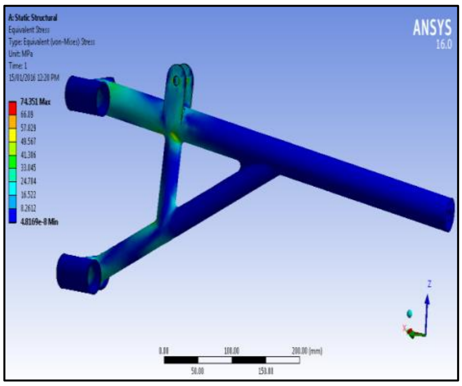

Fig.5 Structural analysis of trailing arms

Conclusions

1) The illustrated Short Long Arm type wishbone suspension design provides efficient handling during cornering and optimized wheel control.
2) The designed Trailing Arm with two camber links provide desired wheel travel and static camber.
3) The obtained wheel travel(front=10in, rear=11.4in) avails isolation from high amplitude obstacles.
4) The designed suspension system maintains undamped natural frequency of 1.3 Hz and 1.38 Hz at front and rear respectively.
5) The quality of the design was assured by performing FEA which portrayed deformation and equivalent stresses well within the desired range.

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