KINEMATICS OF REAR SUSPENSION SYSTEM FOR A BAJA ALL-TERRAIN VEHICLE.

Aditya Shahane, Manasi Kathale, Pratik Rathi and Ashank Gujar
Students, BE Mechanical, Pimpri Chinchwad College of Engineering, Pune, India

ABSTRACT

This Paper studies the functions of rear suspension system of a BAJA all-terrain vehicle and gives a constructive direction to the efforts of making a Durable and agile all-terrain vehicle. After a thorough study of various vehicle dynamics theories, multiple iterations of geometry were made on software such as LOTUS suspension simulation and ADAMS Multi body dynamic tool. The final geometry was manufactured on a vehicle to verify the dynamic characteristics of the vehicle. The vehicle showed the expected results with some marginal error. This paper gives information regarding the nature of the parameters which helped us in achieving the required stability and over steering characteristics of the vehicle.

Keyword: Kinematics, All-terrain vehicle, suspension system, rear suspension, BAJA, Lock differential, turning radius, camber angle, toe, over steer, anti-squat, roll centre, instantaneous centre, ADAMS.


1. INTRODUCTION

For an independent suspension, the assemblage of control arms is intended to control the wheel motion relative to the car body in a single prescribed path. The path may have camber gain, caster change and toe change as prescribed by designer but it still follows only one fixed path of motion relative to the car body. For anybody moving in space relative to other body, its motion can be completely defined by three components of linear motion and three components of rotational motion. A single body is said to have Six degrees of freedom in three dimensional worlds. We know that independent suspension allows one path of motion of the wheel relative to the body. Another way to say the same is that suspension provides five degrees of restraint. Therefore, the study of independent suspension geometries is to determine how to restraint the knuckle to limited motion in five directions.
2. FUNCTION OF REAR SUSPENSION SYSTEM

Role of suspension in an all-terrain vehicle can be broadly classified as performance oriented (Handling) and comfort oriented (Ride). The comfort oriented goals include isolation of shocks and vibration from road undulations and Performance oriented goals are to maintain durability, agility and speed of the vehicle on all kinds of challenging terrains.

2.1 Kinematics designed to assist oversteer.

When rate of change of slip angle of the rear wheels is greater than that of front wheels then the slip angle steer at the rear predominates, this phenomenon is called as oversteer.

![Figure 1](image-url)

Figure 1 Curvature responses of neutral steer, understeer and oversteer vehicle at a fixed steer angle.

All-terrain vehicles usually run a lock differential/spool to achieve traction on all kinds of terrain. Using this type of drive reduces the handling characteristics of the vehicle making it hard to turn in sharp corners. The All-terrain vehicle is usually run on terrains where it may require to manoeuvre through tight turns. This drawback of the vehicle is taken care by suspension system by introducing over steer in the Vehicle.

2.2 Provide longitudinal stability to the Vehicle.

All-Terrain vehicles have a high centre of gravity due to higher ride height which is a functional requirement of the vehicle. This higher centre of gravity induces higher body pitch in longitudinal direction due to acceleration and braking. Acceleration causes the rear suspension system to squat which induces negative camber on the wheels, bumps out the suspension and reduces grip on the front wheels making the vehicle slow on the track.

This drawback of having a higher CG is overcome by the suspension system.

2.3 To incorporate drive shaft in rear geometry.

Most of the All-terrain vehicles are rear wheel drive, in this case half shafts are used to transfer power to the wheels. The main advantage of using half shafts is that they are light in weight and fit in Independent rear suspension system properly. The half shaft has to move with the suspension linkages as it connects gearbox and wheel hub to transfer drive. This acts as an additional link to the suspension system and the kinematics have to be designed to fit in the shaft.

Above are the main roles of the rear suspension system that are expected to perform. These roles are a function of various parameters such as ICR of suspension linkages, roll...
centre of the sprung mass with respect to unsprung mass, weight distribution, pitchcentre, camber gain Dynamic toe change etc.

3. DESIGN OF REAR SUSPENSION
The contributions of above mentioned parameters in fulfilling the roles of suspension are as follows:

3.1 Kinematics designed to assist over steer.
Following parameters affect over steer characteristics of the vehicle.

3.1.1. Weight distribution
The weight distribution is the vertical static weight on front and rear tyres of the vehicle. In rear wheel drive vehicle, the weight on the rear axle is more than that on front wheels so while going through steady state cornering the rear wheels tend to lose contact at lesser lateral acceleration than the front wheels and the rate of change of slip angle at rear increases causing the vehicle to over steer. Increasing the weight on rear to a large extent will tend to decrease the over steer characteristics as the front tyres may lose grip due to less vertical reaction.

3.1.2. Camber Gain
In accordance with SAE terminology camber angle is defined as the angle between a tilted wheel plane and the vehicle. The camber is positive if the wheel leans outward relative to the vehicle, or negative if it leans inward.

A cambered rolling pneumatic tire produces a lateral force in the direction of tilt. When this force occurs at zero slip angles, it is referred to as camber thrust. A lateral force component also occurs at slip angles other than zero. This phenomenon of camber thrust can be utilized in All-Terrain vehicles with spool differentials to induce over steer in the vehicle.

Kinematics of the rear suspension are so designed that the outer wheel shows positive camber and inner wheel shows negative camber. This nature of camber is same in case of front suspension so care is taken that the magnitude is higher on rear wheels.

3.1.3. Instantaneous centre of Rotation (ICR)
Instant means particular position of linkage and centre refers to projected imaginary point that is effectively the pivot point of the linkage at that instant. When we connect a line between upper and lower control arm they will usually intersect at some point. This intersection is an instantaneous centre.\[1\]
If this projection is done in front view IC defines rate of camber change rate. If you replace the control arms of suspension with a single link that ran from knuckle to IC, the amount of camber change that was achieved would be [1]

\[ \text{Camber Change} = \arctan \left( \frac{1}{\text{Length of IC arm}} \right) \]

So, a smaller arm will have higher rate of change of camber and vice versa.

3.1.4. Roll centre height
Roll centre height is found by projecting a line from the centre of the tire ground contact patch through the instantaneous centre. This is repeated on both sides of the car. Where these two lines intersect is the roll centre of the sprung mass of the car, relative to the ground.[1]
The roll centre establishes a force coupling point between the unsprung and sprung masses. When a car takes turn, the centrifugal force at the CG can be translated to the roll centre if appropriate force and moment as shown. Higher the roll centre smaller is the rolling moment and higher is the roll stiffness, lower the roll centre higher is the roll moment and lower is the roll stiffness. The roll moment varies directly with the distance of the roll centre from the CG. Now this trait in combination with camber gain can be used to get decent amount of over steer in the vehicle. \[1\]

**Figure 6** Roll centre height at front and rear of vehicle.\[9\]

The roll centre at the rear is supposed to be lower than the front (as shown in above figure) in order to induce more roll moment at the rear. As the rear starts rolling the weight in the rear as transferred to the outer wheels (which have positive camber) and it has higher traction than the inner wheel. This increased traction at the outer wheels magnifies the lateral forces arising due to camber thrust and the vehicle over steers.

### 3.1.5. Toe Change

Toe change is a major parameter in turning a vehicle. To assist over steer dynamic toe change needs to be added in the kinematics of the suspension. This nature of the dynamic toe change should be such that it introduces toe out in bump travel and toe in in droop travel.

As the vehicle corners the outer wheel experiences a bump and the inner wheel experiences droop so both the wheels are pointing away from the centre of the curve. As front wheels always point inside the turn and with inner wheels pointing outside as discussed above the vehicle will over steer.

The above are traits of kinematic parameters which help in over steering a vehicle besides the above there are some other physical parameters which can help over steering a vehicle. Some of them are:

- Tire pressure
- Spring Stiffness
- Type of plies in tire

### 3.2 Provide longitudinal stability to the vehicle.

As mentioned earlier it is inevitable to have a high CG in an ATV because of high ride height. This introduces pitching problem in the vehicle during acceleration and braking. The vehicle squats during acceleration this may cause loss of traction on front wheels and difficulty in handling the vehicle. And diving of vehicle during braking would produce excessive camber and also bump out the springs.
This drawback of higher CG is overcome by introducing “anti” features in suspension kinematics. The anti-effect in suspension is a term that actually describes the longitudinal to vertical force coupling between the sprung and unsprung masses. It results purely from the angle or slope of the side view swing arm. Suspension “anti’s” do not change load transfer under steady acceleration or braking. The amount of anti in suspension changes the amount of load going through the springs. If the suspension has 100% anti, all longitudinal load transfer is carried by control arms and none by the suspension springs.[1]

In case of rear wheel drive vehicles anti squat feature are incorporated which reduces bump travel, during acceleration avoids pitching and maintains traction on front wheels.

3.3 To incorporate half shaft in the rear geometry.

Most of the Baja all-terrain vehicles are rear wheel drive and half shafts are used to transmit power from gear box to the wheel hub. These shafts move up and down along with the wheel travel i.e. they behave as a link in the suspension system. So, in order to get the required kinematics and also incorporate the shaft the shaft axis when extended must pass through the instantaneous centre of suspension arms.

![Kinematic model of rear suspension in ADAMS](image1)

Above is Kinematic model of rear suspension system of an all-terrain vehicle made in Adams view. The Red Links are suspension links and the yellow link is the shaft. The shaft is connected with a universal joint at each end to permit angular misalignment while rotating both of the joints are out of phase in order to maintain constant velocity during suspension travel. A line extending from the shaft axis intersects the ICR of suspension links and this allows the system to rotate about a single point without disturbing the kinematic behavior of the system.

![Redundant mechanism](image2)
Most of the times, it is not possible to pass the shaft axis through the ICR because of assembly constraints. The above figure shows the shaft whose axis does not pass through the ICR. This makes the mechanism redundant as shown by the message in the message window. It is not possible to move a redundant mechanism.

![Final rear suspension model in ADAMS view](image)

This problem is solved by using a different type of constant velocity joint called as the tripod joint. The tripod joint provides rotational as well as translational degree of freedom which allows the shaft to slide inwards and outwards as the suspension links move through their suspension travel. This provides freedom to design the geometry and removes one constraint of the process.

4. CONCLUSION
Designing the kinematics of rear suspension of an all-terrain vehicle is always a challenging task. It is the complete study of the vehicle dynamics theories and the effect of the important parameters that influences stability of an all-terrain vehicle. Paper throws light on the important parameters like weight distribution, camber gain, ICR, Roll center height and toe change which allows the vehicle with lock differential to negotiate the turn with a smaller turning radius by displaying oversteering characteristics. Moreover, a half shaft has to be incorporated in the rear suspension as a suspension element and to reduce the redundant mechanism which can be facilitatied in the ADAMS Software.

REFERENCES


[10] ADAMS multibody dynamics Software.
