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Fine-Tuning Of the Suspension System of Baja ATV

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ABSTRACT
As defined by the American National Standards Institute (ANSI), All-Terrain Vehicle is a vehicle that travels on low-pressure tires and designed to handle a wider variety of terrain. Since it is made to run on different types of terrain, thus stability, vehicle behaviour and driver comfortability in the vehicle are the foremost problems. Once the ATV is manufactured it difficult to change the design according to the track condition but through, proper adjustments and tuning of suspension system like by changing the spring stiffness, problems can be resolved and also the steering problems i.e. understeer, neutral steer, oversteer can also be corrected.
Key words: Center of gravity, Damping ratio, Flat ride, Natural frequency, Roll axis, Ride rate, Roll gradient, Spring ratio.

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I. INTRODUCTION

As an ATV vehicle is made to run on different types of tracks i.e. muddy, sand loops, hilly roads etc. They should provide driver comfortability and performance at these rough tracks. A fine tuning of the suspension system is the resolution of the all these problems related to vehicle handling, stability and driver comfortability.

As tuning of suspension is a wide field of research and it also alters vehicle to vehicle. It is an iterative method. Here this discussion is limited to the All-Terrain Vehicle.

II. IMPORTANT PARAMETERS

Before starting the tuning of suspension system, one should be familier with various significant parameters and their effects on the vehicle. During the tuning, these parameters acts as the variables and the change in single parameter have the significant effect on the vehicle performance and its behaviour. These are:

1.1 Centre of Gravity : It is the point at which the entire weight of a body may be considered as concentrated so that if supported at this point the body would remain in equilibrium in any position

1.2 Spring rate (K_s): Rate of change of load of a spring per unit deflection taken as a mean between loading and unloading at a specified load. It is generally measured in N/mm.

1.3 Wheel rate (K_w): The change of wheel load, at the center of tire contact, per unit vertical displacement of the sprung mass relative to the wheel at a specified load.

Wheel rate, $K_w = K_s * MR^2 * ACF$

1.4 Ride rate (R): The change of wheel load, at the center of tire contact per unit vertical displacement of the sprung mass relative to the ground at a specified load.

Ride rate, $R = (K_w * K_t) / (K_w + K_t)$

1.5 Roll center: The point in the transverse vertical plane through any pair of wheel centers at which lateral forces may be applied to the sprung mass without producing suspension roll.

There are two separate roll centers for the Front and Rear suspension system.

1.6 Roll axis: It is a line joining the Front suspension roll center with the Rear suspension roll center.

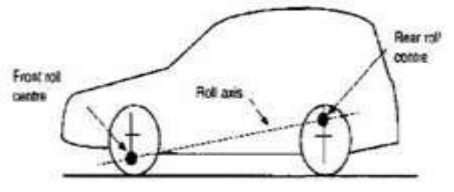


Fig 1 Roll Axis

If the roll axis is dipping at the front then vehicle tends to Unersteer. And if it is dipping at the rear than, vehicle tends to Oversteer.

1.7 Roll stiffness (K): The rate of change in the restoring couple exerted by the suspension of a pair of wheels on the sprung mass of the vehicle with respect to change in suspension roll angle.

1.8 Roll Gradient: The rate of change in the suspension roll angle with respect to change in steady-state lateral acceleration on a level road.

$\acute{\phi}_Y/A_y = (-W \text{ x } H) / (K_F + K_R)$

1.9 Cornering stiffness: The negative of the rate of change of lateral force with respect to the change in slip angle, usually evaluated at zero slip angle.

III. METHODOLOGY

During the dynamic condition, various departments of the vehicle should work in harmony with each other. When a vehicle runs on a Off-road track, there are plethora of vibrations and forces coming on the suspension system. So, there should be a proper synergy of the various parameters which makes the ride comfortable and keeps the tires in contact with the ground.

During the tuning, three most important factors are taken into considerations:

1.10 Proper Design consideration and compatibility with other departments

Design considerations of suspension system totally varies from vehicle to vehicle type and its purpose of usage.

Based on the various design considerations, a durable and dynamic suspension geometry is designed in the LOTUS SHARK v5.01. While designing the suspension geometry, proper considerations should be given to the wheel alignment parameters and compatibility with the Steering system. As these factors along with the Suspension System defines the dynamic behaviour of the vehicle.

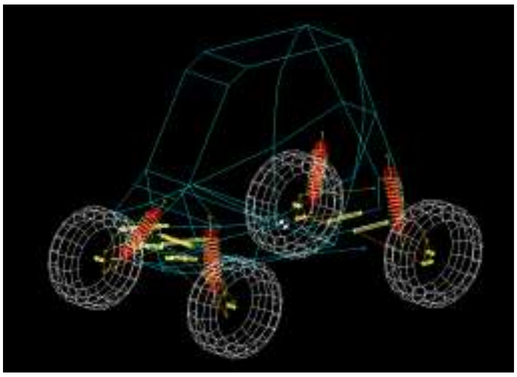


Fig. 2 Suspension Geometry in LOTUS SHARK v5.01

To check the compatibility with the steering system, check for these factors:

1.10.1 Check for Ackermann Percentage change

Steering system should have nearly 100% Ackermann percentage in both static and dynamic conditions. Since the Ackermann percentage changes with the rack travel, thus it should be conformed that it has little change with respect to the static design.

1.10.2 Check for the Bump and Roll steer

When the wheel goes in the Bump and Rebound, there are the toe changes in wheel which disturb the vehicle handling. Thus, there should be minimum toe change during bump and rebound of wheels and similarly during the rolling of vehicle, there should not be any toe change.

Toe change can be adjusted by altering the height of the Rack height and by having the rack inner pivot point in the plane of suspension mounting on the frame.

1.11 Finalizing the Dynamic parameters on the Basis of Forces acting on it and its usage:

Once the geometry is finalised as per the design considerations and various wheel parameters value, forces on various control arms can be calculated by the Truss method.

Depending upon the ride height and arrangements of sub-systems of the vehicle, let it has a mass on single wheel as M. Then taking the dynamic load factor of X, find the total verical force coming on the spring.

Force, $F = W_F * X *$ Motion ratio

Spring rate, k = F/ (spring displacement)

Roll stiffness $k_{\phi f} = 0.5*K_W*(F_f)^2$

Let us assume that vehicle is tracing a circular path of radius R with velocity V.

Centrifugal force on CG = $4MV^2/R$

Roll angle, $\acute{\phi} = (-W \text{ x } H)A_Y/(K_F + K_R)$

And also find out the roll gradient from there.

$\acute{\phi}_Y/A_y = (-W \text{ x } H)/(K_F + K_R)$

Requirement	Value in deg/g
Very soft–Economy and basic family transportation	8.5
Semi soft – Middle market sedans	7.0
Firm- Domestic sport sedans	5.0
Extremely firm – Very high performance sports	3.0
Hard – Racing cars only	1.5

Table 1 Typical roll Gradient values

For an All-terrain vehicle, it should lie between 3.0 – 5.0.

Also find out the weight transfer in the Front and Rear of the vehicle during the cornering as it decides the stability of the vehicle. During cornering, weight is transferred from the inner wheels to the outer wheel due to the centrifugal forces acting on the CG of vehicle. The condition at which there is no or negative normal reaction at any wheel, that wheel will lift off from the ground and that's the starting of rolling of vehicle.

Weight transfer during cornering at Front, $\Delta W = W* \frac{AY}{TF}*\{\frac{H*KF}{KF+KR-W*H}+\frac{B*Z}{L}\}$

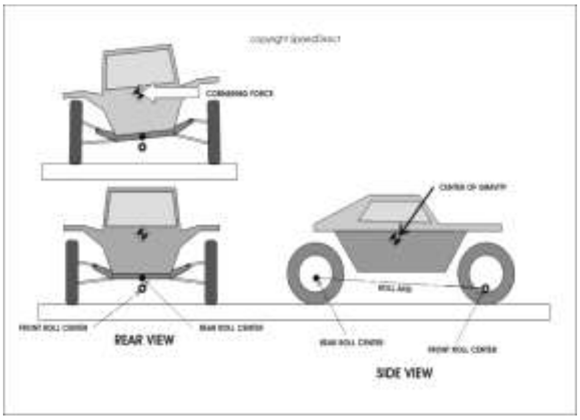


Fig.3 Effect of Cetrifugal force on C.G

- This value of weight transfer should not exceed the 60% of W.
- For the minimum weight transfer, there should be minimum distance between CG and roll axis (H). Roll axis is the line joining the Front roll center and Rear roll center

If the front end of vehicle is having higher roll stiffness, then there is more weight transfer at that end.
Since, we have finalized the suspension design, thus major changes in the parameters related to the geometry can not be made, although minutiae changes can be done. Thus by changing the spring stiffness for the Front and Rear suspension, get the favourable values at which the weight transfer is minimum and also vehicle should not have high value of roll gradient.
Now for that stiffness calculate the undamped natural frequency of the spring at both Front and Rear end.

$$f = = 1/2\pi(\sqrt{\frac{Ks}{m}})$$

and then damped frequency from the formula given below

$$f_{d,} = f\sqrt{(1-ς^2)}$$

here, ς is the damping ratio and given by $= C/2\sqrt{(M/K)}$
As per the Janeway Criteria, human body have the different range of resonance frequency for the different parts of the body.

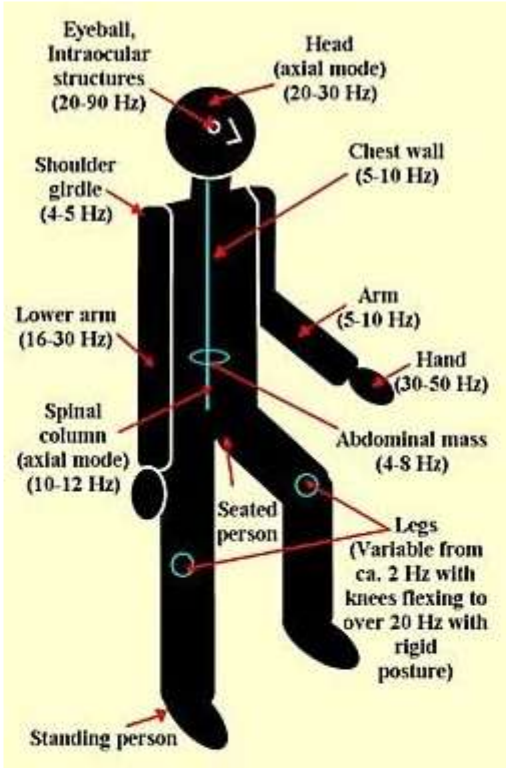
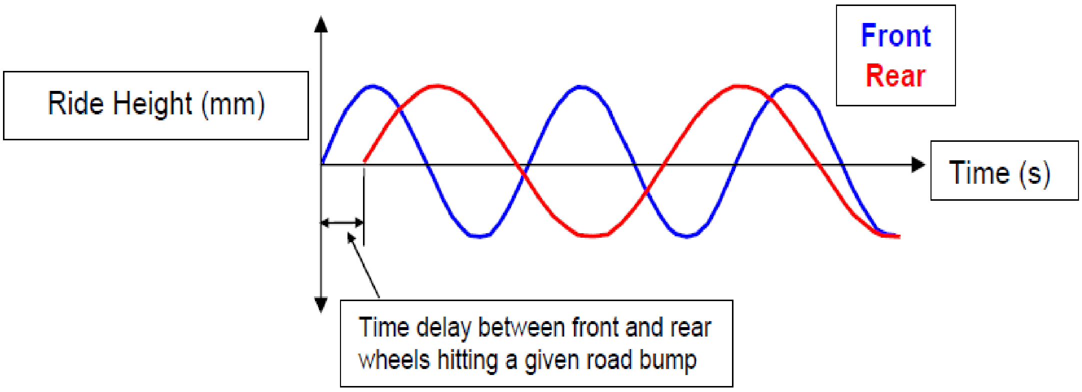


Fig 4 Human parts Resonance Frequency

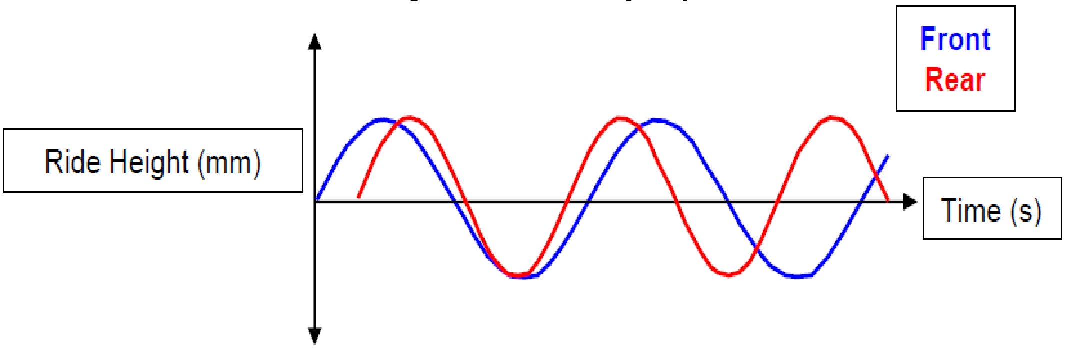
For the better ride comfortability, the natural frequency of spring should lie between 2.0 - 3.2 Hz and damping ratio in between 0.3 - 0.6 for better driver comfortability.
When the parameters are such that, the ride natural frequency of the vehicle matches with the human walking frequency and the driver feels comfortable during riding.

1.12 Check for the Flat Ride Concept:
As per the Flat Ride concept, the natural frequency of the Rear Suspension system should be greater than the Front Suspension system because when bump always hits the front axle first and then rear axle.
This leads to the vibrations in the front part of the vehicle and then after some time delays, in the rear part of the vehicle.

If the Flat ride concept is not followed, then vehicle undergoes the pitching motion and it will not settle down easily leading to the undulating ride.



Higher Front Ride Frequency



Higher Rear Ride Frequency

Fig 5 Explanation of Flat Ride Concept

Thus it is always suggested that the natural frequency of the rear suspension should be 10 - 20 % greater than the front.

Now, since the weight of the vehicle and other parameters are fixed, thus by changing the spring stiffness of the Front and Rear can get the desired behaviour and ride comfortability from the vehicle.

IV. CONCLUSION

After following the desicribed preocedure there is a drastic chang e in the behaviour of the vehicle as compared to without tuning the suspension system. This methodology is used in the tuning of the BAJA SAE INDIA vehicle by the Team Benign Beaders.

Fig. 6 Practical implimentation on BAJA SAE 2017 ATV vehicle

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