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Optimization of Double Wishbone Suspension System by Replacing its Upper Arm by Single Member in ATV

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***Abstract*— ATV refers to All Terrain Vehicle. It is also known as quadricycle, quad and quad bike. Used by single operators. It is designed in such a way that it can handle wider variety of terrain. Suspension system is one of the most imperative sub-systems of an automobile. Its elementary function is to quarantine the driver from the road shocks and bumps and maintain the contact between road and the vehicle. It carries out optimization computing for the suspension based on the target of minimizing the WEIGHT and COST. In this report we optimised the double wishbone suspension system by replacing its upper arm by a single member which results in decrease of weight and cost of the system. MSC ADAMS software is used for simulation of double wishbone suspension geometry. Objective is optimizing the front upper control. A-arm is converted into a single member and the optimization result improves the suspension system performance in a certain extent. CATIA is used for modelling and after the modelling geometry is imported in ANSYS for structural analysis. While simulation of suspension geometry the parameters considered for the result purpose are Camber Angle, Caster Angle, Kingpin Inclination, Roll Steer, Scrub Radius, Percent Ackerman.**

Keywords*— Camber angle; Caster angle; Toe; Kingpin Inclination; Roll steer;scrub radius

I. INTRODUCTION

Suspension system of All Terrain Vehicle is one of the most critical systems that need to be designed for better stability and comfort for the operator. Suspension system is generally designed in relationship with the steering 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. 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). All the ATV prefers the Double wishbone suspension system.

II. DOUBLE WISHBONE SUSPENSION

Double wishbones are the most ideal suspension. It can be used in front and rear wheels, it is independent and most important; it has near perfect camber control. For 40 years and even today, this is the first choice for racing cars, sports cars and demanding sedans. Double wishbones suspension has been very popular in American cars.This suspension almost use in all ATV's. ATV means all terrain vehicles. The early ATV‟s were mainly used for agricultural purpose only. But now the definition of ATV is changing. Many countries are allowing ATVs as commercial vehicle, though with the regulations on its use and safety. Now days, ATVs are generally used in defense and sports application redefining the ATV. Now the ATVs are also coming with durable roll cages, added safety of seat and shoulder belts and higher ground clearance making it more rugged vehicle. The rear cargo deck is more useful for hauling camping gear, bales of hay, tools and supplies making it suitable for exploring back country, riding sand dunes, hunting, fishing and camping. ATVs Sport models are built with performance, rather than utility, in mind. To be successful at fast trail riding, an ATV must have light weight, high power, good suspension and a low center of gravity ATV concerns in 3.4offroading and in this case suspension is the most important system for the drivers comfort in offroading conditions. In off-road terrain the track consists of all kinds of obstacles that could easily bind up the suspension of any road vehicle. Thus, to make the vehicle compatible to off-road conditions it is necessary to design a suspension system that can handle the roughest of bumps without affecting the vehicle stability and at the same time also provide a smooth ride to the driver. The suspension geometry should be such that it doesn‘t undergo drastic changes during wheel travel or heave.

Figure 1 : Double wishbone suspension system

III. PARAMETERS

Different parameters of the double wishbone suspension are camber, caster, toe, steer axis inclination.

These are the parameters which we have to consider as a result after the optimization. There are lots of parameters but we have to check only for these because of their importance.

Camber

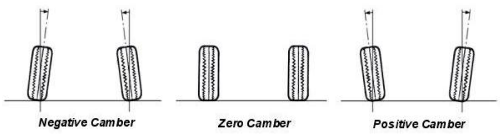

Figure 2: Camber angle

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Figure 2 shows various kinds of camber angles. Camber is the angle of the wheel relative to vertical, as viewed from the front or the rear of the car. If the wheel leans in towards the chassis, it has negative camber; if it leans away from the car, it has positive 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. Tires develop maximum cornering force at a small negative camber angle, typically around negative 1/2 degree. When cornering the body of the car will start rolling, inducing positive camber. Negative camber will compensate this effect. Result in more grip and stability while cornering. Negative camber creates a force on the wheels called "camber-thrust". Going straight Left and Right will be in balance and the car goes straight creating better straight stability. Then the camber-thrust will cause the car to make a sharper turn, pushing the car inwards which helps at cornering. In general negative camber is preferred in any circumstances.

Caster angle and caster trail

Figure 3 shows the caster angle. The caster angle is defined as the angle between the steering axis and the vertical plane viewed from the side of the tire. The caster trail is defined as the distance at the ground between the center of the contact patch (also known as wheel contact point) the point at which the steering axis intersects the ground. The caster angle is positive when the steering axis (the steering axis is defined as a line that passes through the ball joints on the upper and lower control arms) is inclined in such a way as it points to the front of the vehicle; a good way to remember positive caster angle is from the forks of a motorcycle (they are always inclined to the front). The caster angle defined in the figure above is a positive caster angle. Positive caster trail occurs when the steering axis intersects the ground at a point that is in front of the center of the contact patch.

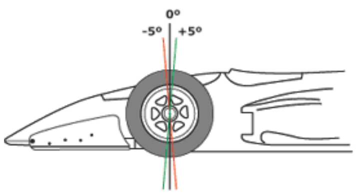

Figure 3:Caster angle

It is important that the caster angle and caster trail be positive because both of these quantities will affect the aligning moment. The aligning moment is the moment that will act against the driver as he/she is trying to steer the vehicle. It is important that this moment acts against the driver so that when the driver lets go of the steering wheel it will correct itself; the moment will force the tire to re straighten itself. Caster trail is important because it defines how much of a moment will be applied to the steering axis; as the caster trail increases, the moment arm increases and thus the moment acting on the steering axis will increase. It is this moment that is acting to self center the tire if the caster trail is positive. However, if the caster trail is too large the driver will have a difficult time trying to turn the wheels about the steering axis.

Steering Axis inclination

Figure 4 shows the line passing through the kingpin and the perpendicular to the ground, looking at the vehicle from the front is steering axis. The inclination of this axis tends to lift the car while steering. This is because while steering wheel turns about axis. The scrub radius Introduces a steering torque which tends to create a moment arm (proportional to scrub radius) while braking and accelerating. During braking the moment arm help in moving the vehicle in straight line. More caster angle or mechanical trail will give rise to more steering effort.

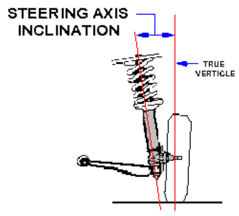

Figure 4: Steering Axis Inclination

Like SAI, caster angle also lifts the vehicle but in opposite manner i.e. it rolls the vehicle to the left in right turn causing diagonal weight transfer. If the caster is positive at the one side and negative on the other side with same magnitude, then there will be only rise and fall of vehicle on steering, no diagonal weight transfer. Camber Caster and SAI are very much related to each other. If there is no caster and no SAI there will be no change in camber while steering. If there is SAI but no caster angle, while steering positive camber will be induced in outer wheel. If there is no SAI but have caster angle then, negative camber will be gained in outside wheel. So SAI and caster are kept in such a way that they can compensate each other camber gain, by providing their individual function.

Toe

Figure 11 is about Toe. 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. Toe settings affect three major areas of performance:

1. Tire wear
2. Straight line stability
3. Corner entry handling characteristics

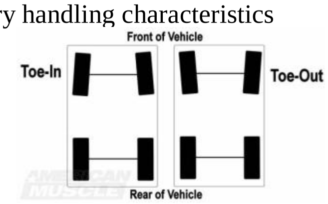

Figure 5: Toe

For minimum tire wear, power loss, the wheels on a given axle of a car should point ahead, but when the wheel on one side of the car encounters a disturbance, that wheel is pulled rearward about its steering axis. If it's a minor disturbance, the disturbed wheel will steer only a small amount, perhaps so that it's rolling straight ahead instead of toed-in slightly. The wheels absorb the irregularity without significantly changing the direction. In this way, toe-in enhances straight-line stability.

If the set up is with toe-out, the front wheels are aligned so that slight disturbances cause the wheel to assume rolling directions that describe a turn. Minute steering angle position will cause the inner wheel to steer in a tighter turn radius than the outer wheel. The amount of toe can be expressed in degrees as the angle to which the wheels are out of parallel.

IV. MATERIAL USED

Different types of materials are studied but out of all AISI 4130 Chromyl Steel is used because of the following features.

Mechanical Properties of Chromyl steel

The mechanical properties of AISI 4130 alloy steel are outlined in the following table.

Table 2: Mechanical properties

Properties	Metric
Tensile strength ,Ultimate	560 MPa
Tensile strength, yield	460 MPa
Modulus of elasticity	190-210 GPa
Bulk modulus	140 GPa
Shear modulus	80 GPa

V. ADAMS SIMULATION

We used the ADAMS simulation for fixing the position of new member. After doing primary iteration we get three initial position of the upper wishbone which was about the optimized. Three positions are as follows:

- In Center
- Front Of Spring
- Behind The Spring

For center position we can’t select this position because of the spring position. If we want to select this position we have change the spring position because of which stiffness can be change depending upon the angle of the spring mounting. Figure 6 shows the modified member is behind the spring. Results we get for this geometry are negative caster and positive camber. This is not suitable for our geometry as we are designing for the all terrain. Figure 7 shows modified in front of spring geometry. For in front of spring the basic result we got was the positive caster and negative camber which are good for the rough terrain. So this position decided and then further optimization of this position to get the final position of optimized geometry.

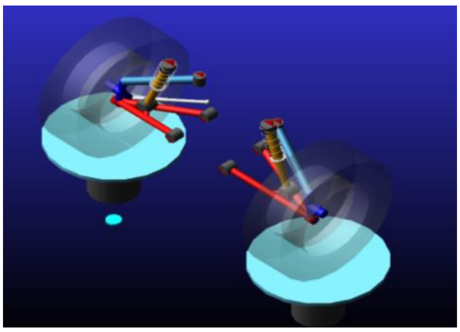

Figure 6: : Behind the Spring

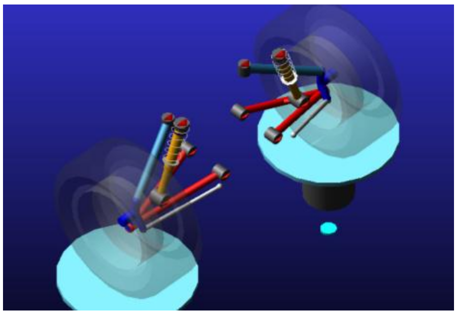

Figure 7: In front of spring geometry

Figure 7 shows modified in front of spring geometry. For in front of spring the basic result we got was the positive caster and negative camber which are good for the rough terrain. So this position decided and then further optimization of this position to get the final position of optimized geometry.

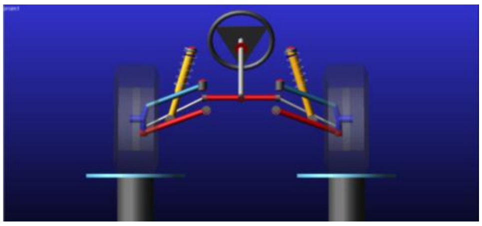

Figure 8: Front View of Geometry

Figure 8 shows the front view of optimized double wishbone suspension geometry. Member in red colour is lower control arm (Lower Wishbone). Member in sky blue colour is Upper control arm (Upper Wishbone).Member in Yellow colour is spring (Strut). Member in blue colour is knuckle.

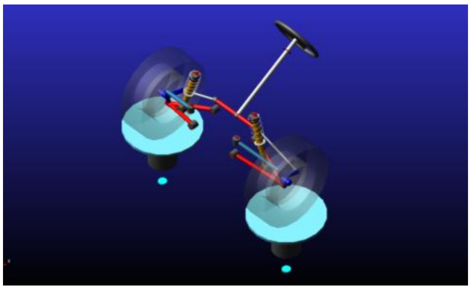

Figure 9: Isometric View of Geometry

Figure 9 shows the isometric view of optimized double wishbone suspension system.

VI. DESIGNING AND ANALYSIS.

A. Input Parameters

For wishbone-

Material: Chromyl Steel

Density: 7850 kg/m^3

Poisson’s ratio: 0.3

Tensile Strength: 560 MPa

For Knuckle-

Material: Aluminum

Poisson’s ratio: 0.34

Density: 2689.8 kg/m^3

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Young's Modulus: 68.3 MPa

For Spring-

Material: Steel Alloys

Poisson's ratio: 0.3

Density: 7850kg/m^3

Tensile strength: 560 MPa

Table 3: Lists the Material Used for Different Components of the Suspension

NO.	DESCRIPTION	Qty.	MATERIAL
1.	Knuckle	2	Aluminum
2.	Spring	2	Steel
3.	Wishbone	2	Chromyl Steel
4.	Nut	10	Steel
5.	Bolt	10	S.G Iron
6.	Racket	4	Steel

VII. CAD MODEL

Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or othermanufacturingoperations.The term CADD (for Computer Aided Design and Drafting) is also used. The Knuckle is modeled in CAD software CATIA V5R20 is used for modeling. The isometric view of Knuckle is shown in figure 19 and isometric view of the wishbone shown in figure 20. Isometric view of new wishbone shown in figure 21 and figure 22 shows isometric view of c section plate.

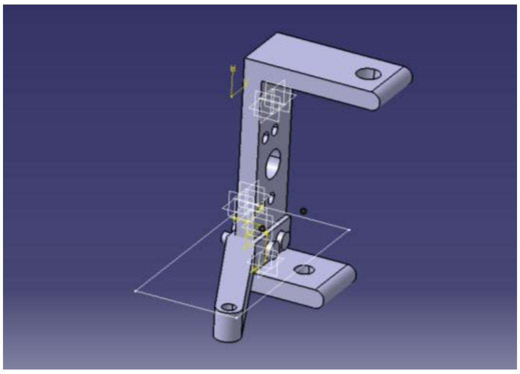


Figure 10: Isomeric view of Knuckle

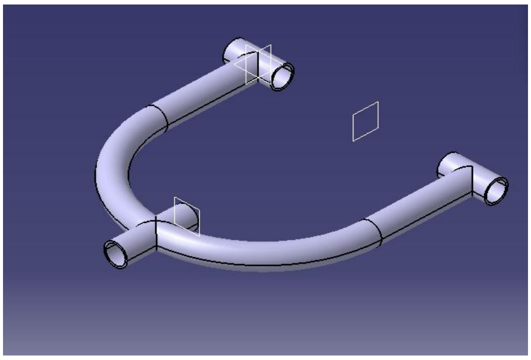


Figure 11: Isometric view of old Wishbone

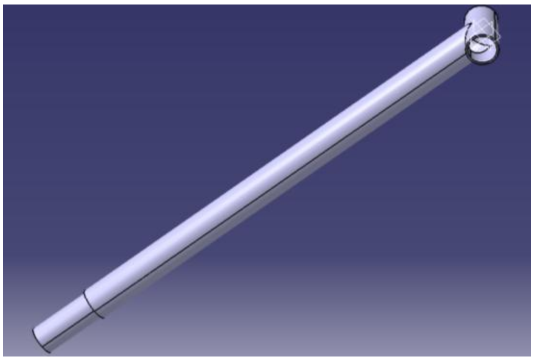


Figure 12: Isometric view of new wishbone

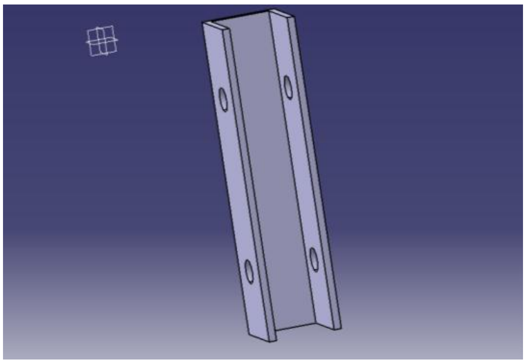


Figure 13: Isometric View of C Section

VIII. FEA DETAILED PROCEDURE

Importing CAD model: The Knuckle, spring and Wishbone assembly generated in CATIA was converted to universal format (STP) and imported into ANSYS 15.0 workbench.

Element Selection: From library element is selected.

Material Properties: After element selection material properties are provided as input. This includes Poisson's Ratio, Young's Modulus etc.

Meshing: ANSYS Meshing is general-purpose, intelligent, automated high-performance product. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it. The power of parallel processing is automatically used to reduce the time you have to wait for mesh generation. This involves breaking down the component into small discrete elements. Hence the component when meshed entirely made up of a small element. Finer mesh provides more accurate results but take a lot of time while a coarse mesh takes less time but sacrifices on accuracy.

Application of Forces: For the Upper Wishbone, from the previous year Baja team, the force acting on the upper wishbone is 2.5g of the total weight of the buggy without driver. Weight of vehicle without the driver is 180kg.

Force on the upper wishbone is 180*2.5*9.81 = 4410N

For the Suspension Mounting Bracket, Force of 1500N is applied on components in lateral and longitudinal direction.

For the mounting of new member we have used C section. Force applied on the C section is 5000N.

For the Knuckle, the force applied is 3800N is lateral direction. Brake Force is 3800N towards the ground.4800N is on knuckle hole of ball joint.

Solution: After applying the forces solutions are obtained.

Results: Stresses are plotted as result.

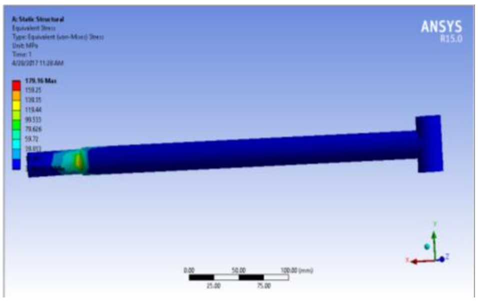


Figure 14: Stresses on New Wishbone

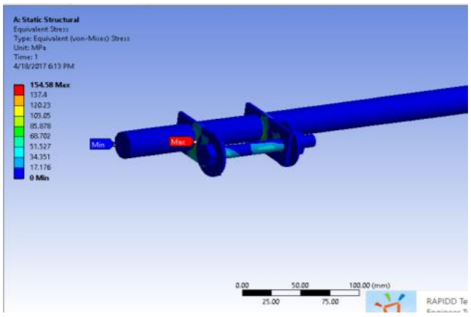


Figure 15: Stress on Bracket of new wishbon

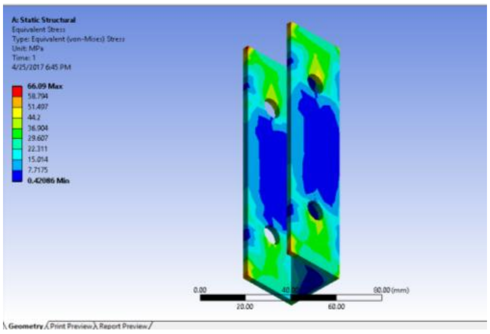


Figure 16: Stress on C Section

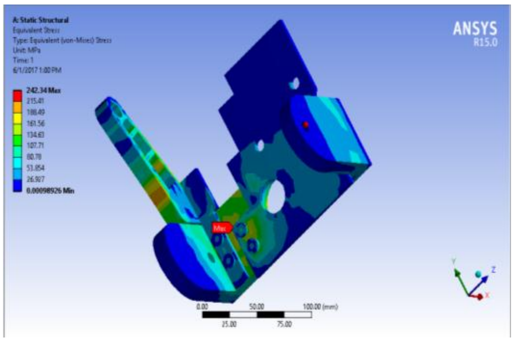


Figure 17: Stress on Knuckle

Von Moses Criteria: For structural (stress) analysis Von Moses Criteria is used. The Von Moses Criteria is based on distortion theory. Von Moses Criteria suggest that when the equivalent tensile stress (also called as Von Moses Stress) exceeds the yield (Tensile) strength of the material and when material fails.

For Safety, $\sigma_e \leq \sigma_y$

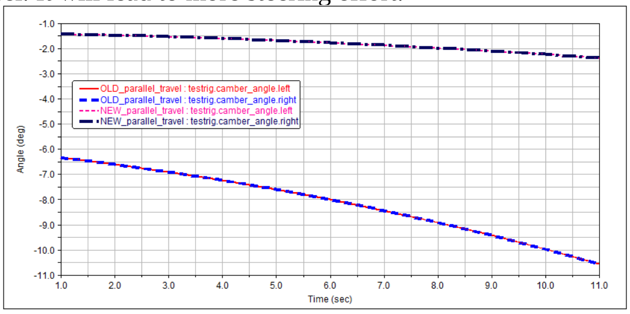
Where σ_e is the equivalent stress and σ_y is the yield stress.

Table 4: Result Table

COMPONENT	STRESS ON COMPONENT	ALLOWABLE STRESS	FOS
WISHBONE	179.06MPa	435MPa	2.45
C SECTION	66.9MPa	370MPa	5.56
KNUCKLE	242.38MPa	480MPa	1.98
SPRING BRAKET	154.58MPa	370MPa	2.39

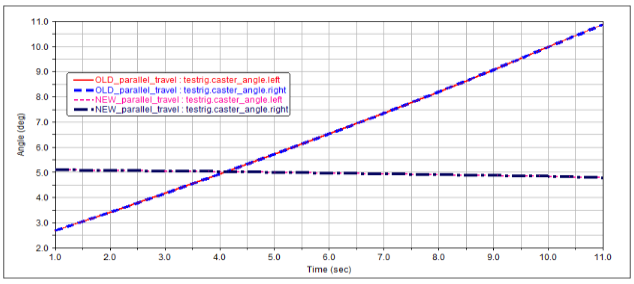
RESULTS

Graph 1 is Length (mm) vs. Camber (degree) angle showing for both new and old geometry. Camber change for old geometry is from -1 to -3 degree and camber change for new geometry is form -6 to -9.5 degree. Both values are in negative. Negative camber provides better cornering stability and traction while cornering. It will also reduce the life of the wheel. It will lead to more steering effort.



Graph 1: Camber Angle

Graph 2 is Length (mm) vs. Caster (degree) angle showing for both new and old geometry. Caster change for old geometry is from 4 to 5 degree and caster change for new geometry is form 3 to 10 degree. Both values are in positive. More the caster angle value more will be the steering comfort. Caster angles over 7 degrees with radial tires are common. As we have radial tire so we have selected the range of 3 to 10 degree so that it will help the steering system.



Graph 2: Caster Angle

Graph 3 is Length (mm) vs. Kingpin Inclination (degree) angle showing for both new and old geometry. Kingpin Inclination for old geometry is from 15 to 17 degree. Kingpin Inclination for new geometry is form 7 to 8 degree. Both values are in positive. Camber Caster and kingpin angle are very much related to each other. If there is no caster and no king pin angle there will be no change in camber while steering. If there is kingpin angle but no caster angle, while steering positive camber will be induced in outer wheel. If there is no king pin angle but have caster angle then, negative

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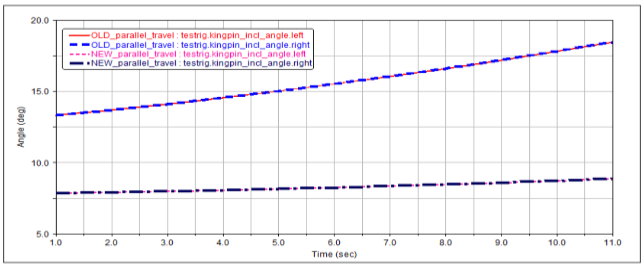
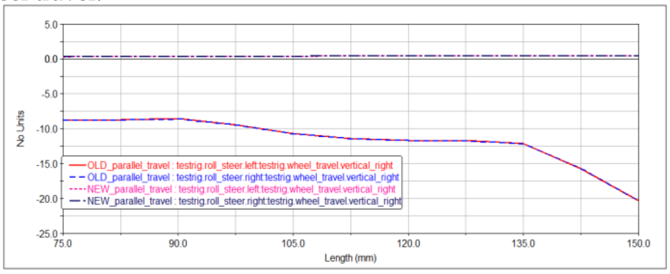
camber will be gained in outside wheel. So kingpin angle and caster are kept in such a way that they can compensate each other's camber gain, by providing their individual function.



Graph 3: Kingpin Inclination

Graph 4 is Roll steer graph. By comparing old and new graph we can notice that the second geometry is more stable. Roll steer is usually measured in degrees of toe per degree of roll, but can also be measured in degrees of toe per metre of wheel travel.



Graph 4: Roll Steer

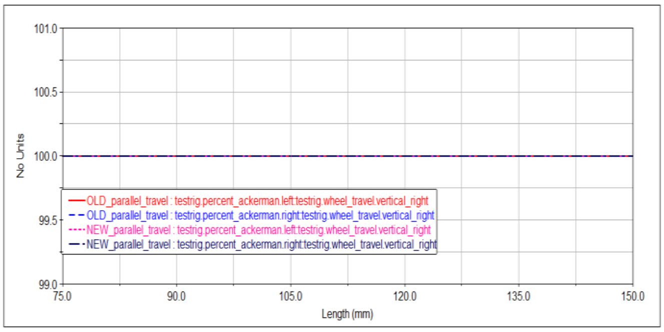
Graph 5 is Percentage Ackerman graph. For both old and new Geometry Percentage Ackerman is 100 % which indicates that both geometry are stable and steering geometry for this suspension geometry will give you good result.

0%: Parallel Steering

Below 100%: Understeer

At 100%: True Ackerman

Above 100%: Oversteer



Graph 5: Percent Ackerman

CONCLUSIONS

From the results, it is clear that the new optimized geometry is ready to be installing in the vehicle that is Baja's buggy. Same material used as the team Dirtcross used that is chromyl steel 4130.

All the primary factors of suspension kinematics and kinetics are achieved with the new optimized geometry. This makes it suitable for the ATV.

Other vehicle where this geometry can be install

- Auto rickshaw
- SUPRA competition car
- Electric cars

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