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DESIGN PROGRAM OF STEERING MECHANISM FOR ALL-TERRAIN VEHICLES

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ABSTRACT This Study named "Design Program of Steering System for All-Terrain Vehicles" is to ensure the most efficient steering assembly selection for an All-Terrain Vehicle. In this process various parameters are kept in mind for an effective selection of Steering system. The Steering system uses a Rack and pinion gearbox for Steering along with this Ackerman geometry is being used for the steering assembly. In this assembly modified Column of Tata Nano car is used which is connected to Rack and Pinion Gearbox by a Universal Joint. The Steering wheel is so designed to meet the weight reduction requirement along with keeping in mind the driver comfort. The Rack and pinion gearbox is connected with Steering arm by the Tie Rods. Tie Rods and Steering arm are being designed and analyzed for their load bearing Capacities.

KEYWORDS : Rack And Pinion Gearbox, Ackerman Steering Geometry, All-terrain Vehicle, Tie Rods, Steering.

INTRODUCTION

The design of steering system has an influence on the directional response behavior of a motor vehicle. The function of the Steering system is to steer the front wheels in response to driver inputs in order to provide overall directional control of the vehicle. However, the actual steering angles are modified by the geometry of the suspension system, reactions and the geometry of the steering system and the reactions of Powertrain if the vehicle is front wheel drive.

The rack and pinion system has gained popularity for the passenger cars as well as for the because of the advantages like a simpler design and better suitability of front wheel drive system and adaptability to vehicles without frames. The Gearbox is the primary means for the numerical reduction between the rotational input from the steering wheel and rotational output about the steering axis. The steering wheel to road wheel angle ratios normally vary with the angle, but have a general value of the order of 15:1 commercial passenger cars to 4:1 for racing cars. Initially, all Rack and Pinion systems are available that have fixed ratio and any changes in the ratios are obtained by changing the geometry. The lateral acceleration produced by the gearbox is relayed through linkages to steering arms on the left and right wheels. The kinematic geometry of the relay linkages and steering arms is usually not a parallelogram (Which would produce equal left and right steer angles), but rather a trapezoid to more closely approximate " Ackerman" geometry which steers inner wheel to greater angles than outer wheels while turning.

METHODOLOGY:

The Process followed for design and fabrication of Steering system involves following steps.
1. Analysis of Previous year's Vehicle
2. Defining the Objective for New vehicle.
3. Market Survey for the Components used.
4. Steering Geometry Iterations.
5. Design Validation.
6. Steering system parts fabrication.
7. Steering system Assembly.

Steering Parameters:

LHD OR RHD	CENTER
STEERING RATIO	17:1
TURN LOCK TO LOCK REVOLUTION	3.5rev
GEOMETRY	ANTI- ACKERMAN
COLUMN	TATA NANO STEERING COLUMN
RACK AND PINION	TATA NANO RACK AND PINION
STEERING WHEEL DIAMETER	14 INCHES

Table: Analysis Of Previous Year's Vehicle.

OBJECTIVES:

1. Outer Turning Radius -: 2.5m
2. Lesser Lock to Lock rotation
3. Lower Steering ratio.
4. Modified Column for weight reduction.
5. Ackerman Steering Geometry.
6. Optimized steering wheel dimension for driver comfort.

MARKET SURVEY:

After doing market Surveys following Components were selected for the steering system.
1. Customized Rack and Pinion Gearbox. (10:1)
2. Modified Tata Nano Steering Column.
3. Stainless Steel Pipes for Tie rods.

S.no	Parameters	Value
1	Rack Size	15inches
2	Rack size(eyetoeye)	14inches
3	Travel centre to lock	2.24inches
4	Travel lock to lock	4.48inches
5	Pinion Radius	0.53inches

STEERING GEOMETRY:

The Ackerman steering geometry is selected for the vehicle because this geometry enables the vehicle to turn about the common center i.e. without skidding of the tires and also the Ackermann geometry is favored for the slow speed vehicle as the speed limit for the vehicle we are designing is 60 km per hour so it's the obvious choice. This geometry provides excellent control for low-speed maneuvering.

Vehicle Design Parameters	
WHEELBASE	65 inch
TRACKWIDTH	55 inch
RACK LENGTH	14 INCHES FROM CENTRE TO CENTRE OF ROD END
GROUND CLEARANCE	15 INCHES
KPI TO KPI DISTANCE	46.7 INCHES
SCRUB RADIUS	11 cms

Table-: Vehicle Design Parameters.

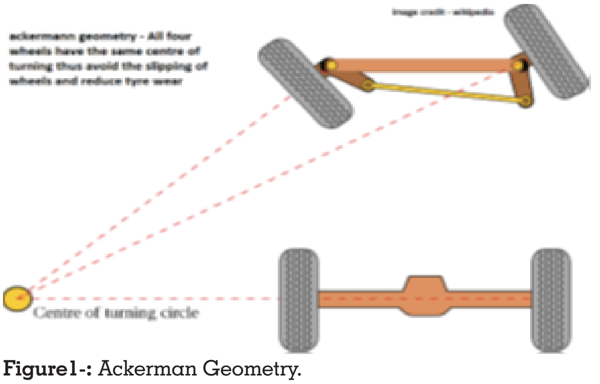

Figure1-: Ackerman Geometry.

In Ackerman geometry the inside wheel turns more than the outside wheel [3]. In this geometry, the rack is placed behind the front axle and if we extend the steering arms then they will meet at the extension of rear axle during turning, the point is the instantaneous center about which the whole vehicle turns without skidding [3].

Inside And Outside Steering Angle:
As the requirement for our vehicle is to keep turning radius low so it is decided that the outside turning radius of our vehicle should be 3 meters.

$$R = \frac{b}{\sin\emptyset} + \frac{a-c}{2},$$ (By geometry figure3) (I)[1]

$$\frac{3000}{25.4} = \frac{65}{\sin\emptyset} + \frac{55-46.7}{2}$$

$$\emptyset = 34.77\ deg.$$

Fig-:2 Rack and pinion.

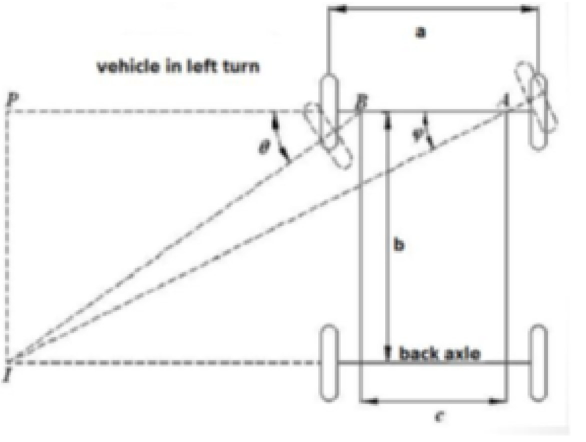

Figure-:3 Vehicle InturnI Aisturningradius.

Now by correct steering geometry,

$$\cot\emptyset - \cot\theta = \frac{c}{b} \qquad \text{(ii) [1]}$$

$$\cot 34.77 - \cot\theta = \frac{46.7}{65}$$

$$\theta = 54.17\ deg.$$

Total steering angle =34.77+54.17= 88.9deg.

Steering Ratio
This is defined as ratio of angle turned by steering wheel in lock positions to the sum of total steering angle of tires[3] so,

Total angle turned by steering wheel
=trackwidth/(2*3.14*pinionradius)
=4.48/(2*3.14*.53)=484.33deg.
Steering ratio=484.33/88.9

Steering ratio=5.44:1

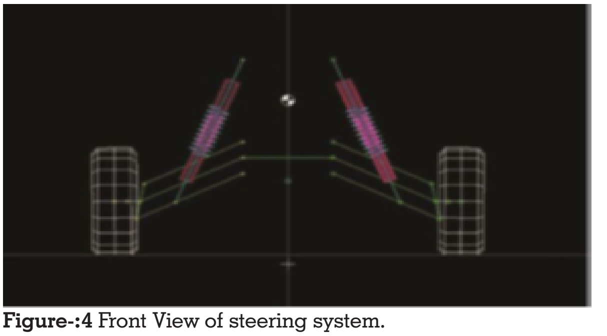

Figure-:4 Front View of steering system.

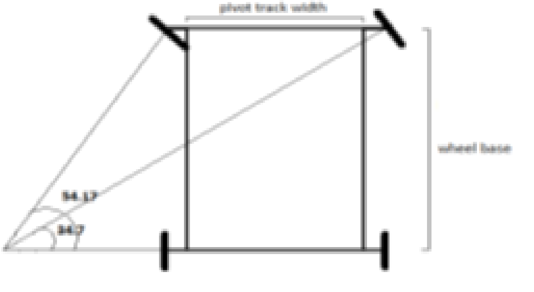

Figure-:5 Vehicle steering angle.

Position Of Rack
After several iterations for Placement of rack on LOTUS Simulation software according to the requirement of steering angles, we came to following data for positioning of rack.

Rack Height-:46cm from Ground

Rack from FBM-: 3inches

Steering arm length from KPI to Pivot Point = 4.3inches.

Ackerman angle=

$$\frac{KPI\ to\ KPI\ Distance}{2*wheelbase},$$

(iii)[1]

AckermanAngle= $\frac{46.7}{2*65}$ =19.75deg.

Ackerman Percentage=91%

(This is calculated in LOTUS)

Rack travel=4.48inches from lock to lock.

Tie Rod Length
Steering Arm Length=4.3"
(After various iterations on lotus and manually to achieve the required angles)

Distance between IBJ and OBJ horizontally is = 23.35 – 1.5 – 7 = 14.85"

But the tie rods are not in the plane of steering arm, tie rods inclined at an angle of 17deg downwards from horizontal and 5deg towards forward i.e. tie rods are not parallel to front axle.(as per the design of vehicle)

Therefore,thelengthoftierodsis
14.9/(cos17*cos5)=15.64"

The suspension arms used in the vehicle are parallel to each other and are of equal length i.e. the I Centre of the arms are at infinity,

To reduce the bump steer the tie rods must be parallel to suspensionA-armssothatduringthebumptheI-Centreoftierods also meets the I-Centre of A-arms at infinity. In this way the arc traveled by tie rods and the arms were equidistant to each other during the travel of suspension and there was no force generated along the rack to produce bumpsteer.

Determination Of Steering Effort

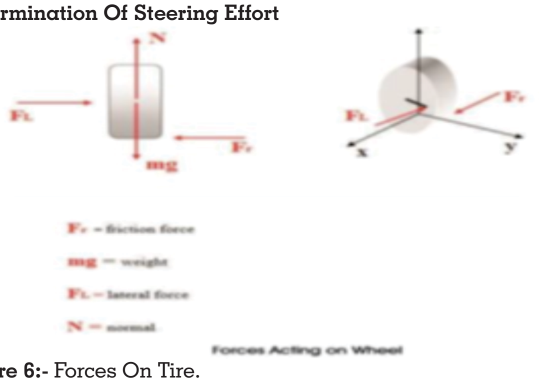

Figure 6:- Forces On Tire.

Steering effort is defined as the effort to be made by the driver in turning the steering wheel. This can be calculated in either static condition i.e. when the vehicle is stationary and in dynamic conditions. Steering effort is maximum when the vehicle is stationary.

Mass of vehicle=223+70(with driver of 70kg)

Mass of Vehicle=293kg.

Mass acting on Centre of gravity=258.44

Taking moment about B (in Figure09)

258.44*26.93=RA*65

RA=1050.39N

Reaction at each tire
(RA/2+massoftire)*9.81
=1050.39/2+8.14*9.81
=605.04N

When the car is stationary, the forces in all directions are in equili brium (Figure7)

$\sum$ Fx=0;FL=FR(1)

$\sum$ Fy=0;N=mg(2)

The tires used for the vehicle are mud tires and coefficient of friction between tires and rolled gravel ground is 0.6 (data provided by various tire manufacturers)
The friction for ceat the tire is
=μ*Reactionateachtire

=.6*605.04

=363.024N
While turning the steering wheel the torque will transmit to pinion and then to the steering arms and this torque should be equal or greater than thefrictionalresistanceofthegroundto be able to turn the tire.

From this, the value of steering arm torque is calculated by multiplying length of steering arm with the friction force FR.

Steering Arm (SA)torque=363.024*.11=39.93N-m

Force per pendicular to steering arm(Fs1)

FS1=39.93/0.11=363N

Since tie rod is not in the plane of steering arm and it's also not parallel to front axle so components of this for ceis taken

Therefore, component of force below tie rod in the plane of steering armis Fs2

FS2=FS1/cos24.75=399.71N

Tie rod is at an angle of 17deg above from the plane of FS2 (Accordingtorackplacementandsteeringarmplane)

FST=FS2/cos17=403.31N

Force along rack(Frack)

Frack=FST/cos17=421.73N

To rque acting on the pinion

=Frack*radius of pinion
=421.73*13.47*10-3
=5.68N-m

To rqueon steering wheel=To rque onpinion

Steering wheel torque=5.68N-m

The amount of force or effort required on the steering wheel is calculated by dividing the to rque by the radius of steering wheel

Steering effort=5.68/(0.127)
Steering effort=44.72N

This is the force when applied by the driver will turn the tire in static condition; the effort required in dynamic condition will be less than static effort.

Nature of Steering(Oversteer or Understeer)

Over steer–

Over steer is the condition when the vehicle at the time of cornering steers more than the angle provided by the driver through steering wheel. This happens when the rear tires losses their traction before the front tires because of the centrifugal force acting on them. When rear tires losses their traction and they slip out of the corner thus inducing more steer to the vehicle.(Figure8)

Under steer–

This condition appears when the front tires losses their traction before the rear tires and slip out of the turn during cornering at large speeds and smaller curves. In this case, the vehicle follows a larger curve for cornering then it actually should. In Understeer, the driver needs to steer the vehicle more than the required angle for making the turn.

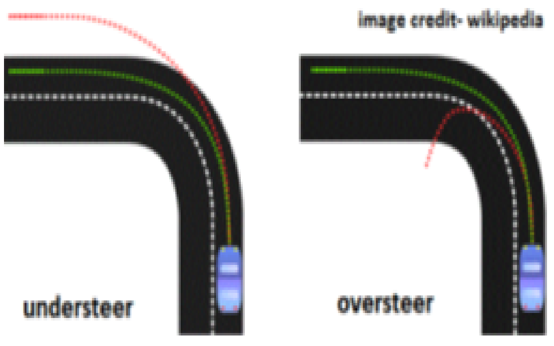

Figure-:7 Over Steer And Under Steer

When ever the vehicle is taking a turn an outward lateral force act on the vehicle due to centrifugal effect also called as the cornering force.

Sum of lateral forces is equal to mass of vehicle time's centri petal acceleration.

$$cornering\ force = M * V^2 \quad \text{(iv)[3]}$$

FYF=Rear axle lateral force

FYR=front axle lateral force

FY=FYF+FYR[3]

Calculation at 2.5m radius and 25km/h speed i.e.6.944m/s.
FY=223*6.944*6.944/2.5

FY=4301.14N

Sprung mass of vehicle=210kg

Sprung mass at front axle and rear axle

$$M_f = 210 * \frac{c}{b}$$

$$M_r = 210 * \frac{c}{b}$$

Using above equations

Mf=87kg

Mr=122.99kg

At fixed radius of 2.5m anddifferent velocities values of FYF and FY Rare as follows

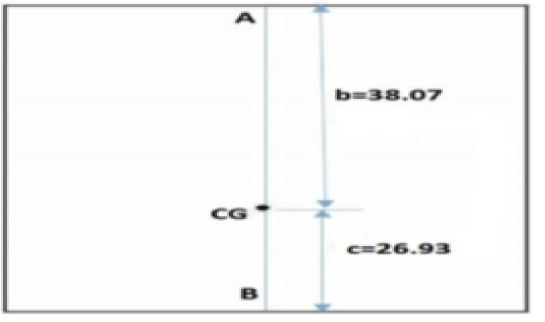

Figure08:- CG from rear and front axle.

Atv=0m/s

FYF=Mf*V2/R=0
FYR=M*V2/R=0

Similarly,
Atv=1.39m/s
FYF=67.23N
FYR=95.05N

Atv=2.78m/s
FYF=268.94N
FYR=380.2N

Atv=4.16m/s
FYF=602.23N
FYR=851.36N

Atv=5.55m/s
FYF=1071.92N
FYR=1515.35N

Atv=6.99m/s
FYF=1700N
FYR=2403.72N

Now Average values
FYF=742.06Nor168.07lbs.
FYR=1049.136Nor237.62lbs.

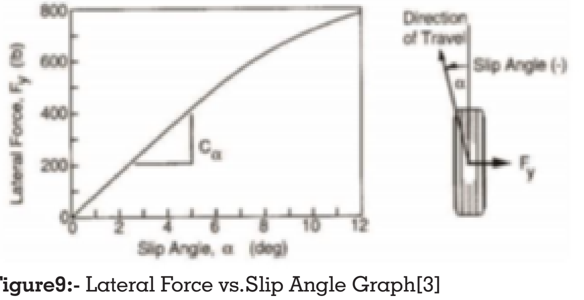

Figure9:- Lateral Force vs.Slip Angle Graph[3]

From the above graph [3] the values of slip angle is inter polated as
α_f=1.73deg
α_r=2.5deg

Cornering stiffness(Cα)

$$C_\alpha = \frac{fy}{\alpha} \quad \text{(v)[3]}$$

Cαf=742.06/1.73=428.93N/deg

Cαr=1049.136/2.5=419.65N/deg

Weightonfrontaxle(Wf)=MF*9.81=853.47N

Weightonrearaxle(Wr)=MR*9.81=1206.53N.

Over Steer Condition

If $\frac{Wr}{C\alpha r} > \frac{Wf}{C\alpha f}$ [3] then vehicle will oversteer otherwise it will have a tendency of Under steer.

$\frac{Wr}{C\alpha r} = 2.875, \frac{Wf}{C\alpha f} = 1.99$

Since the value satisfies the condition of oversteer, therefore the vehicle has the tendency of oversteering at cornering.

Required Angle at the time of maximum turn

Velocity (m/s)	FYF (N)	SlipAngle (deg)	Required angle (deg)
0	0	0	54.17
1.39	67.23	0.16	54
2.78	268.9	0.7	53.4
4.167	602.2	1.5	52.67
5.55	1071.9	2.7	51.47
6.94	1700	3.96	50.21

Table-: Required Internal Wheel Steer Angle at Maximum Turnat Different Speeds.

Abovetableshows,thatatthetimeofsharpcorneringthevehicleis oversteering i.e. the rear tires loss their traction before front tires and slip angles are induced and required angle for maximum turning reduces because the vehicle is steering more than the driver'sfeedatthesteeringwheel.

Materials Used For Different Steering Parts

S.no	Component	Material
1	Steeringarm	Hardenedmildsteel
2	Tierods	StainlessSteel-304
3	C-Clamp	StainlessSteel–304
4	Rack	Al-Alloy
5	Steeringcolumn	StainlessSteel

Table-: Materials Used for Different Parts.

CONCLUSION

The objective of designing effective steering system for an all-terrain vehicle is accomplished with the application of engineering principles and with the use of Simulation Software like LOTUS, The vehicle's steering system was designed for optimal performance. The Design is validated in dynamic conditionsandeffectivechangesaredonewithimprovementsin design we have achieved a steering ratio of 5.5:1 which is better than our objective of 8:1 and great improvement from previous steeringratio.TheSteeringsystemissodesignedtominimizethe bump steer and we are able to achieve this. Bump steer in the vehicle is almost negligible. Steering system involves many factors and other parameters of the vehicle such as suspension, weightdistribution,andtransmissionsystem used. All of these shouldbekeptinmindwhilecalculationisdone.Steeringsystem optimization is highly iterative in nature where different iterations are performed on software and manually before deciding the best solution, which fulfills the vehicle requirement andobjective.

Calculation of steering involvesalotofunknownvariablesand that is why we need to assume certain parameters about the geometry and then perform the iterations and check if the assumption of thesystemmeets the objective or not.

Based on the requirements and performance of the vehicle the wayofcalculations can vary and should meet the objective.

This paper showsthemethodweusedtocalculatethevaluesfor ourvehicle accordingtoourvehicledesign and we meet the entireobjective we set for our vehicle.

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