

# Mathematical Study and Design of Ackermann Steering Geometry in Four Wheeler

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**Abstract** - Control is main essential part of automobile, without control we can't handle vehicle. Control system includes control of steering and brakes of vehicle. The main function of steering system is to convert the rotary motion of steering handle into angular displacement of front wheels. Nowadays most of the four-wheeler and trike (tadpole) are having steering system based on Ackermann principle. Some of the tilting tricycle design using a tadpole trike configuration and it needs an adequate steering system that can be synergized with tilting mechanism. In present work, new mathematical model is developed in order to design steering geometry mentioned above considering different steering parameters. This mathematical model includes some equations according calculation parameters. By solving this equation we can get different steering parameters and considering optimum steering geometry with respect to steering effort and Ackermann %. This model can be using in Ackermann as well as reverse Ackermann steering geometry of four wheeler as well as trike by applying this model on front and rear steering design.

**Key Words:** Ackermann Principle, Mathematical Model, Steering Geometry, Inner Wheel Angle, Outer Wheel Angle, Ackermann %, Critical Speed, Steering Ratio.

## INTRODUCTION

### STEERING SYSTEM

The main function of steering system is to convert the rotary motion of steering handle into angular displacement of front wheels. The steering mechanism must also maintain the straight-ahead motion of vehicle while it encounters road bumps and pot-holes and must operate with minimum effort during operating vehicle.

### FUNCTIONS OF STEERING SYSTEM

- To turn the vehicle at the will of the driver.
- To control the direction of automobile vehicle.
- To control the wear and tear of vehicle tyres.

- To provide directional stability and rolling action of wheels on the road surface.
- To achieve the self-righting effect.
- To multiply the effort of the driver for easy operation.

### EFFECT OF BAD STEERING SYSTEM OVER THE DRIVER

- Hard Steering.
- Abnormal tyre wears.
- Shimmy front wheels
- Poor recovery of turns.
- Tyre squeals on turning.
- Side to side wandering of vehicles.

### REQUIREMENTS OF STEERING MECHANISM

- The front wheel should be roll without lateral skid during taking turn.
- The tyre must have good elasticity that on turns, these may follow an arc of greater radius than the stiff tyre.
- The wheels must be come automatically to straight position after negotiating the turn. When going on straight road, the wheel must maintain the natural position.

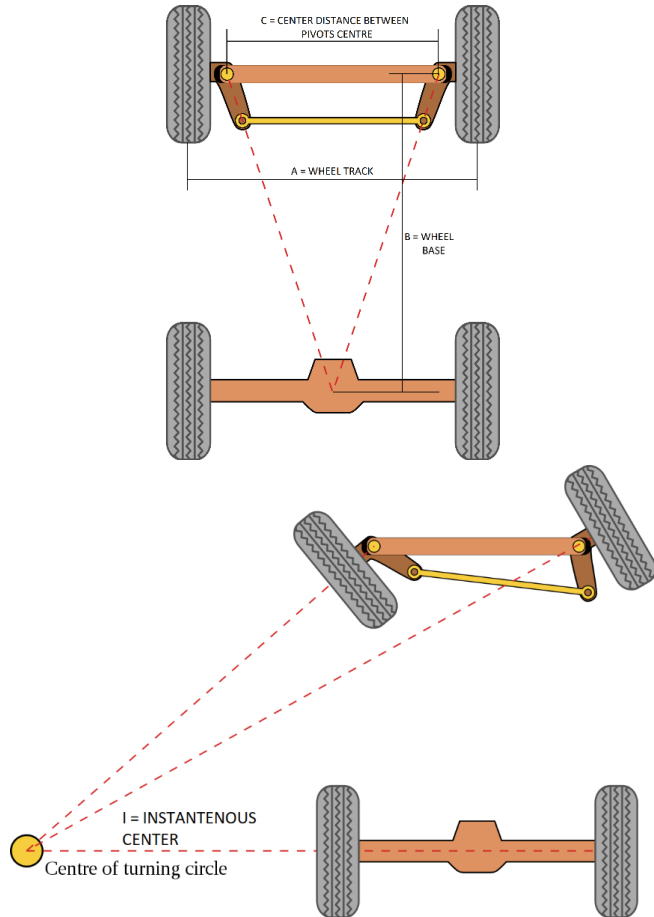
### OBJECTIVE OF ACKERMAN STEERING MECHANISM

Ackerman steering geometry is most widely used in commercial vehicles. The intention of ackermann geometry is to avoid the need for tyres to slip sideways, when following the path around a curve.

### ACKERMAN PRINCIPLE

During the turning the vehicle if I-centers of all wheels meet at a point, then the vehicle will take turn about that point which results in pure rolling action of the vehicle. The condition is called the ackermann condition and this principle is known as ackermann principle.

**FUNDAMENTAL EQUATION FOR ACKERMAN STEERING OF FOUR WHEELER AND TRIKE (TADPOLE)**



**Calculations:**

Terminology:-

Assumed Values for Calculations,

$a = \text{Wheel track} = 1.1684 \text{ m}$

$b = \text{Wheel base} = 1.2192 \text{ m}$

$c = \text{Distance between pivot centers} = 0.9652 \text{ m}$

$\theta = \text{Inner wheel lock angle}$

$\phi = \text{Outer wheel lock angle}$

$\alpha = \text{Ackermann angle or Steer arm angle}$

$T_{IF} = \text{Turning radius of inner front wheel}$

$T_{OF} = \text{Turning radius of outer front wheel}$

$T_R = \text{Average Turning radius}$

Steer Angle or Ackerman Angle,

$$\alpha = \tan^{-1}\left(\frac{c}{b}\right)$$

$$\alpha = \tan^{-1}\left(\frac{0.9652}{2 \times 1.2192}\right)$$

$$\alpha = 21.59^\circ$$

Inner wheel lock angle,

$$T_{IF} = \frac{b}{\sin\theta} - \frac{a-c}{2}$$

$$T_{IF} = \frac{1.2192}{\sin\theta} - \frac{1.1684 - 0.9652}{2}$$

(As per requirement of Turning Radius >4m. We Consider Inner turning radius is 2)

$$\sin\theta = \frac{1.2192}{2} - \frac{1.1684 - 0.9652}{2}$$

$$\theta = 30.52^\circ$$

Outer wheel lock angle,

Now by correct steering geometry,

$$\cot\phi - \cot\theta = \frac{c}{b}$$

$$\cot\phi - \cot(30.52) = 0.7917$$

$$\phi = 21.89^\circ$$

Turning radius of inner front wheel,

$$T_{IF} = \frac{b}{\sin\theta} - \frac{a-c}{2}$$

$$T_{IF} = \frac{1.2192}{\sin(30.52)} - \frac{1.1684 - 0.9652}{2}$$

$$T_{IF} = 2.30 \text{ m}$$

Turning radius of outer front wheel,

$$T_{OF} = \frac{b}{\sin\phi} + \frac{a-c}{2}$$

$$T_{OF} = \frac{1.2192}{\sin(21.89)} + \frac{1.1684 - 0.9652}{2}$$

$$T_{OF} = 3.37 \text{ m}$$

Average Turning Radius,

$$T_R = \frac{T_{IF} + T_{OF}}{2}$$

$$T_R = \frac{2.30 + 3.37}{2}$$

$$T_R = 2.835 \text{ m}$$

Ackermann Value,

$$= \tan^{-1}\left(\frac{\text{wheelbase}}{\frac{\text{wheelbase}}{\tan\theta} - \text{track}}\right)$$

$$= \tan^{-1}\left(\frac{1.2192}{\frac{1.2192}{\tan(21.89)} - 1.1684}\right)$$

$$= 33.16$$

Ackermann %,

$$= \frac{\theta}{\text{Ackermann value}} \times 100$$

$$= \frac{30.52}{33.16} \times 100$$

$$= 92.04 \%$$

Critical Speed of Vehicle,

For taking turn at critical speed the outer wheel should not lift off.

$$mv^2 \div R = \mu \times mg$$

$$v = \sqrt{\mu g R}$$

$$v = \sqrt{0.635 \times 9.81 \times 2.30}$$

$$v = 3.78 \text{ m/sec}$$

$$v = 13.61 \text{ km/hr}$$

Steering ratio:

The overall steering ratio is defined as degrees of steering wheel divided by corresponding front wheel angle.

The steering ratio is the ratio of how much the wheel turns to the amount of travel generated in the track.

Approximating maximum turn to be of 90° and steering wheel movement to be 90° the steering ratio can be calculated as,

$$SR = \frac{\text{degrees of steering wheel}}{\text{front wheel turning angle}}$$

$$SR = \frac{90}{90}$$

$$SR = 1:1$$

## STEERING GEOMETRY

### REQUIREMENTS OF STEERING GEOMETRY

- The steering mechanism should be very accurate and easy to handle.
- The effort required to steer should be minimal and must not be tiresome to the driver.
- The vehicle should have a tendency to return to its straight ahead position after turning.
- The steering mechanism should also provide directional stability.

The factors of front wheel geometry are considered for the steering ease, steering stability, tyres wear and the riding qualities of the vehicle. The front wheel geometry depends upon the following factors:

#### 1. Camber :

The camber is tilt of the front wheel from the vertical plane. When the wheel tilt outward at the top then the camber is positive and when the wheel tilted inward at the top then the camber is called negative. The wheels are given positive camber, cause the when vehicle is loaded and rolling along road, then wheels automatically come to a vertical position. The positive camber measured from the vertical plane. The camber angle should not exceed 2 degree, while running.

Positive camber and negative camber tends to cause more rapid tyres wear because load is shared on one side of tyre. Therefore, tyre's life will be maximum when camber angle is in running condition is zero with average road.



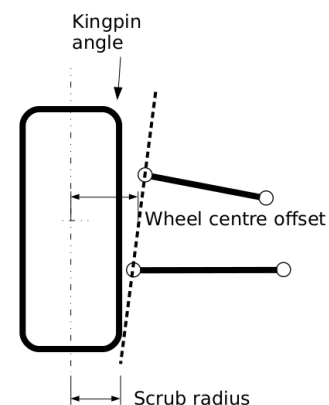
Negative Camber



Positive Camber

#### 2. King Pin Inclination (KPI):

King pin inclination means the inward tilt of king pin from the vertical plane. The amount of KPI is generally kept 7 degree to 8 degree. The KPI, in combination with castor, is to provide directional stability of vehicle. Because of this inclination causes the vehicle to move up and the front wheels are swing away from straight ahead. Weight of vehicle tends to return the wheels back to straight ahead after turn is completed. In modern automobile with independent suspension, King pin is replaced by the ball joints. This term is also known as 'steering axis inclination'.



#### 3. Castor:

The king pin may tilted forward or backward from the vertical line or axis and in plane of the wheel. King pin tilted backward from vertical plane is called as positive castor. Positive castor on the front wheels provide directional stability to the vehicle.

For Positive castor, the vehicle tends to roll out or lean out on turns and case of negative castor, the vehicle tends to back or lean in on turns.



Negative Caster



Positive Caster

#### 4. Toe IN and Toe OUT:

Toe in and toe out have an effect on the car's stability and handling. It is rarely seen a toe out setup on a road going car, maybe a bit on the driven axle, but it is due to the stability issues it brings (road cars tend to be set up very conservatively, giving generally safer and less eventful understeer). Toe out, at least in the front, causes the car to want to be 'all over the place', it won't be good at holding the line, and it will wallow across the road and need constant adjusting. Since this instability gives you a sharper turn-in response, the car will be easier to turn into the corner. Toe-out in the rear would give similar results, but with the rear end being the more unstable part of the car, which would be even worse on the road.



Toe-In



Toe-Out

correct steering geometry. Steering geometry can be optimized by using mathematical equations for ackermann mechanism for different inner wheel angles also we get ackermann percentage from this geometrical equation. To design the vehicle steering (four wheeler), this mathematical model can be applied to rear wheel steering also.

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#### CONCLUSION

By applying and solving above equations of mathematical model for any vehicle like four-wheeler or trike, ackermann steering geometry for any vehicle can be designed mathematically. Above parameters are sufficient to get

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