

# Design of Rear wheel Steering & Braking System for self Propelled Onion Harvester

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**ABSTRACT:** Nowadays, the every vehicle existed mostly still using the front wheel steering system to control the movement of the vehicle whether it is front wheel drive, rear wheel drive or all wheel drive. The basic idea is to provide easy manoeuvrability with effective control. But due to the performance in terms of turning radius and steering at sharp corner rear wheel steered vehicle is always preferred. In this report, the performance of rear wheels steered vehicle model is considered which is optimally controlled during a lane change manoeuvre in low speed agricultural use. In this case rear wheel steer in opposite direction to the final turning direction and allowing much sharper turns. The provision of camber and caster should be provided according to the actual field condition such that there should be straight ahead movement with minimum turning effort. The machine is going to be operated in the field so that maximum speed will in the range of 14 to 15 km/hr. According to that braking time and stopping distance is being calculated for effective braking. The machine should be compact so that frame design based on steering parameters so we decided the compact condition with minimum turning radius.

**KEYWORDS:** Productivity, Rear wheel steering, Steering Mechanism, Turning Radius, Braking Distance

## I. INTRODUCTION

Our challenge is to design the steering mechanism for the agricultural machine with minimum turning radius. In agricultural field, machine has to take sharp turns while ploughing the field also there is space limitation. So it is important to design and develop mechanism which fulfils all requirements. Basic requirement of agricultural machine are it must be robust, stable, reliable and efficient. For this we have applied Ackerman steering principle and rack and pinion mechanism to the rear wheels. Rack and pinion mechanism is simple in construction and more efficient because it has rotary parts instead of sliding parts. Braking mechanism is basically to stop the machine with minimum time and minimum stoppage distance. For that effective utilization of resources with conditioning is being applied.

### 1.1 Problem Statement

During market survey of harvesters we know that customers were emphasized on the minimum turning radius and easy to handle machine. As agricultural machine must have low turning radius and low stopping distance. By considering the bed size and crop properties we have to design the steering and braking system. So that machine easily shifts from one bed to another bed. The bed size of onion field is 450 mm so it became very intricate to shift machine just by front wheel steered vehicle. So we have to go for another mechanism rather than front wheel steering.

Our challenge was to design a braking system gives a good braking efficiency. In most of the agricultural vehicle, the braking system play vital role. Small harvester is equipped with engine braking. It is quite challenging to equipped vehicle with all actual braking just like normal automobile even it is more costly. Thus to overcome all of these problems we have adopted independent braking system. Using simple hydraulic circuit, this system can cock the wheel depending upon steering input which is manually operated. Thus this give advantage of minimizing the turning radius as in normal working condition. However higher braking efficiency not only leads to stopping in shorter time, may also cause injury to the driver due to high decelerating forces. It also causes rapid wear brakes & more risk of losing control of vehicle. Braking efficiency of the order 50-80 enable to stop within reasonable distance. However stopping distance varies with road condition and condition of tires. We have selected the wheels size according to design requirements.

## II. OBJECTIVES

We set our objectives according to market survey, customer demand, field requirement and available resources. Main objectives of onion harvester are

- Best machine field efficiency
- Easy to handle the machine



- Best machine farm efficiency.
- Minimum consumption of fuel during the field operation
- With best crop (Onion) digging ability
- Minimum damage to crop (Onion)
- Reliable operation
- Saves time
- Easy to repair in minimum time
- Adoptable design
- Good material handling and operator field comfort

### III. METHODOLOGY

By understanding the customer voices and product demand related with the onion harvesting machine, we established some factors which can make the machine more optimum, reliable, efficient and cost associative. These factors can be stated as; the machine should have easily serviceable parts in case of breakdown. It should have the best payback period; it should be suitable for different soil conditions,

Table -1: Overall Machine Specifications

Sr. No.	Parameter	Specification
1	Machine Type	4 wheels
2	Overall dimensions (L×B×H)	2602*1336*1500
3	Static Ground Clearance	300
4	Machine weight	570
5	Wheel Base	1900
6	Wheel track width	1125
7	CG height	400
8	Max. Speed	11kmph
9	Working Width	800
10	Working Depth	80

To work on the above factors we decided the strategy to design and fabricate the onion harvester which can perform effectively with most innovative and optimum features.

According to that we divided the machine into different subsystems according to its working principle and mechanism. Following figure gives brief introduction about each system and its features.

- **Digging and Conveyor System**
  - Integrated blade
  - Effective Blade Geometry
  - Adjustable Cutting Depth with Hydraulic Jack Mechanism
  - Better Separating Index
  - Engage and Disengage Mechanism for Conveyor Drive
- **Steering System**
  - Adjustable Camber
  - Effective turning radius
  - Provides better control on uneven agriculture field
- **Power Transmission System**
  - Provide best performance on field by providing effective torque at wheel and best tractive effort.
- **Machine Frame**
  - Provide structural support to the machine



- Provides better ergonomic considerations by providing good visibility assistance, accessibility of controls and safety

#### IV.DESIGN OF STEERING SYSTEM

##### 3.1. Requirements of steering system

- Machine having minimum turning radius
- Less steering effort
- Easy handling and smooth steering
- Steering mechanism is easily adoptable and efficient
- Steering should provide good directional stability it include machine easily return to original position in minimum time.
- The design such that transfer minimum shock to wheels

##### 3.2 Selection of steering mechanism

Why rear wheel steering

- When front wheel are steered the rear wheel get drifted as most of wheels are steady in plane of vehicle and doesn't rotate about KPI
- when rear wheels are steered the tail of vehicle get swing along the turn
- The rear wheel steering was the necessary concept as it allows more space for conveying the onion and shifting the drive train to front wheels and pull system is preferable compare to push system in agro industry.

Table -2: Steering System Specifications

Steering system specification	
Actuation wheel	Rear wheel
Type of steering system	Rack and Pinion type
Inner wheel angle ( $\theta$ )	43 <sup>0</sup>
Outer wheel angle ( $\phi$ )	33.35 <sup>0</sup>
Ackerman %	91%
Turning radius	2.42 m
King pin Inclination (KPI)	8 <sup>0</sup>
Camber	5 <sup>0</sup>
Caster	-3 <sup>0</sup>
Scrub Radius angle	74mm
Track width	850 mm
Wheel Base	1900mm
Steering Gear Box Ratio	18: 1
Steering Arm	150

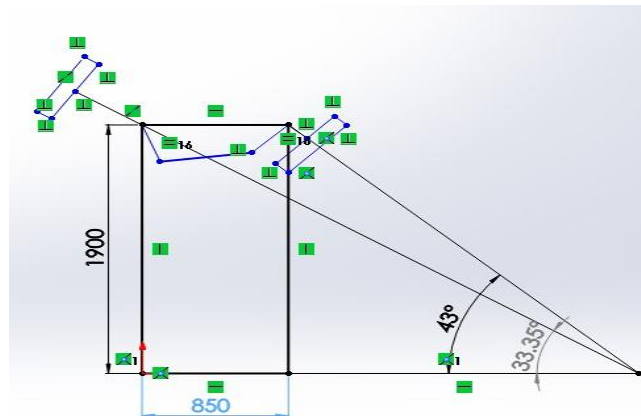


Figure 1. Ackerman steering geometry

### 3.3 Selected Gear Box Type: Rack And Pinion

Rack and pinion provides less mechanical advantage than other mechanisms but less backlash and greater feedback, or steering "feel". The rack carries the full load of the actuator directly so the driving pinion is usually small, so that the gear ratio reduces the torque required. Thus torque may still be substantial.

### 3.4 Selected Steering Ratio and Steering Gear Box: Steering Ratio

Considering the vehicle to be partially a prototype of tractor and partially an ATV, the steering ratio had to be in between 10:1 to 20:1. The steering effort had to be less, looking at the different operation a driver has to do while driving the vehicle and also while harvesting the onions. Various gear boxes of tractors as well as cars were studied. The most suited to ratio is between 15:1 to 20:1 for this vehicle.

### 3.5 Inner Wheel Angle ( $\theta$ ) $43^\circ$

The angle of inner wheel while taking right turn or left by locking steering wheel with extreme position is known as inner wheel angle. We have to minimize turning radius below 2.5 m so by permutation and combination we decided inner wheel angle  $43^\circ$ .

### 3.6 Outer Wheel Angle ( $\phi$ ) $33.35^\circ$

Outer wheel angle has calculated according to predetermined inner wheel angle which is  $43^\circ$ . By using perfect Ackerman steering formula,

$$\begin{aligned} \cot \phi - \cot \theta &= \frac{c}{b} \\ \frac{1}{\tan \phi} &= \frac{850}{1900} + \frac{1}{\tan \theta} \\ \frac{1}{\tan \phi} &= 0.4477 + \frac{1}{\tan(43)^\circ} \\ \frac{1}{\tan \phi} &= 1.5197 \\ \tan \phi &= 0.658 \end{aligned}$$

$$\phi = 33.35^\circ \dots \text{Outer wheel angle}$$

### 3.7 Turning Radius: 2.42 m

The turning radius or turning circle of a vehicle is the radius (or, depending on usage, diameter) of the smallest circular turn (i.e. U-turn) that the vehicle is capable of making.

**Requirement:** The turning radius for this machine was to be kept below 3 m. This was for easy manoeuvrability of the vehicle from onion bed to bed.

### 3.8 Calculations

In steering geometry,  
 Wheel base - 1900mm  
 Wheel track - 850mm  
 Inner wheel angle-  $43^\circ$   
 Outer wheel angle-  $33.35^\circ$   
 According to steering geometry and results,  
 Turning radius - 2.42 m  
 Scrub radius - 74mm



**CAMBER: +5°**

Camber angle is the angle between the vertical axis of the wheels used for steering and the vertical axis of the vehicle when viewed from the front or rear. The positive camber angle gives greater stability on uneven surfaces. Tractors ordinarily designed with considerable amount of camber as they frequently required to operate on uneven surface largely counteracts the tendency of cambered wheels to turn outwards though they were large cones turning around there apexes. Harvester is also works on uneven field so we provide positive 5° camber angle. The correct camber for this vehicle was in between the range of 1.5to 7°.

**CASTOR: - 3°**

Caster angle may be adjusted to optimize handling characteristics for a particular venue. It is the angular displacement of the steering axis from the vertical axis of a steered wheel in a car, motorcycle, bicycle or other vehicle, measured in the longitudinal direction. It is the angle between the pivot line (in a car an imaginary line that runs through the centre of the upper ball joint to the centre of the lower ball joint) and vertical. For agricultural vehicles there is no castor implemented. But considering the ATV condition and requirement of the vehicle for running it in the onion field castor of -3° was decided to be implemented to attain the straight motion of the vehicle while plucking the onions.

**King Pin Inclination: +8°**

The kingpin is set at an angle to the vertical plane when viewed from the front or rear of the vehicle. This angle is known as the king pin inclination. The purpose of the KPI is to produce vertical displacement of the vehicle in during steering in an upward direction. The larger the KPI, the larger the effect. This lifting effect produces a self cantering torque similar to that of caster. The KPI also generates scrub radius. It helps to reduce road shocks such as those caused by holes, stones & high spots

**Scrub Radius:**

The scrub radius is the distance in front view between the king pin axis and the centre of the contact patch of the wheel, where both would theoretically touch the road. It could be positive, negative or zero. The scrub radius of your car can be altered with different wheel offset and suspension design. A negative scrub radius tends to better for braking stability in the event of brake failure or split-μ braking. . A positive scrub radius tends to be beneficial while braking into a turn. Typically, the scrub radius is configured to be as small as possible to minimize the effects under braking, but squirm (from zero scrub radiuses) is also undesirable. The Scrub radius is calculated by graphical method.

**Ackerman Percentage:**

Ackerman percentage decides how much your inner tire turns compared to outer tire. 100 % Ackerman condition is when the turning circles of both inner and outer tire are concentric while 0 % means both circles are the same i.e. inner tire turns the same angle that of outer tyre. In 100 % Ackerman condition the steering arms meet at the center of rear axle. When the Ackerman % is below 100%, the condition is under steer and when the Ackerman percentage is above 100% the condition is over steer.

$$\begin{aligned}
 \text{Ackerman} &= \tan^{-1} \left( \frac{\text{wheel base}}{\frac{\text{wheel base}}{\tan(\text{inner angle})} - \text{track width}} \right) \\
 &= \tan^{-1} \left( \frac{1900}{\frac{1900}{\tan(33.35)}} \right) \\
 &= 47.12^\circ \\
 \text{Ackerman \%} &= \left( \frac{43}{47.12} \right) \times 100 \\
 &= 91\% \\
 91 \% &< 100\% \dots\dots\dots \text{understeer}
 \end{aligned}$$

**3.9 Wheels and Tires**

**Front Tire Selection:-**

Selection of front wheels was according to specification given in the rule book, provided by SAE-TIFAN. These wheels are used where drive is given, here is the specification

- Tire Type = TT
- Outer Diameter = 818mm
- Tire size = 7.5"- 16"
- Pattern =AS504



- Pressure = 65 psi
- Ply rating = 8 ply
- Rim size = 16"

**Rear Tire Selection:-**

By considering the ground clearance which was to be maintained 300mm above the ground, according to the requirements on agriculture field, for better traction, direction stability & to get more grip on uneven agriculture field. From we selected the rear tires of 12". The Dimensions of the REAR TIRES is as follows:

- Tire type = TT
- Outer Diameter = 588 mm
- Tire Size = 6"- 12"
- PLY Rating = 4 Ply
- Rim Size = 12"
- Pattern =AS504
- Tire pressure = 55 psi

**V. DESIGN OF BRAKING SYSTEM**

As front wheels are drive member and maximum speed of harvester is 15kmph so we provide disc brake to front wheels which gives smooth working and minimum stopping distance.

**4.1 Objectives for Braking System**

- To achieve minimum stopping distance.
- High operational speed and less effort required
- Easy to operate and compatible
- Taking into account traffic safety and maintenance.
- Minimum cost of braking assembly
- Leakage proof working

**4.2 Calculations**

**Dynamic load on front wheel,**

$$M_f = \left[ (1 - \varphi) + \left( \frac{C.G.}{W.B.} \right) \times a \right] \times T.W.$$

Where,

C.G = centre of gravity

W.B. = wheel base (m)

T.W. = total weight (kg)

a = deceleration

$\varphi$  = static load distribution

$$\varphi = \frac{Ma}{M} \quad Ma = \text{load on front axle (static)(kg)} \quad M = \text{total weight/ load in (kg)}$$

$$\varphi = 0.4$$

$$\frac{C.G.}{W.B.} = \frac{400}{1900} = 0.2105$$

$$M_f = \left[ (1 - 0.4) + \left( \frac{400}{1900} \right) \times 0.1131 \right] \times 570$$

$$M_f = 355.572 \text{ kg}$$

**Front axle load should not exceed total mass of vehicle,**

Braking torque (Both wheels)

$$B_{Fg} = M_f \times a \times g$$

$$= 355 \times 0.1131 \times 9.81$$

$$= 394.51 \text{ Nm}$$

**Braking force to lock up the wheel**



$$BF_{lock} = Mf \times g \times \mu \quad \text{Where } \mu = \text{coefficient of friction}$$

$$= 355.57 \times 9.81 \times 0.4$$

$$= 1395.25 \text{ N}$$

Torque for front wheel braking,

$$= 1395.25 \times R_{tyre}$$

$$= 1395.25 \times 0.4025$$

$$= \mathbf{561.58 \text{ N-m} \dots\dots\text{torque required}}$$

**Validation of brake torque requirement**

Master cylinder bore = 19.05 mm  
 Area of master cylinder = 285.023 mm<sup>2</sup>  
 Pedal force = 400 N  
 Pedal ratio / leverage ratio = 6:1  
 ∴ Force generated on master cylinder,  
 = 6 × 400 × 0.9  
 = 2160 N

Pressure developed by master cylinder,

$$P_{mc} = \frac{F}{A} = \frac{2160}{285.023} = 7.57 \text{ N/mm}^2$$

Cylinder piston area =  $\frac{\pi}{4} \times (30)^2$   
 = 706.85 mm<sup>2</sup>

Since the number of calliper mounted on each wheel is 2, hence the area is doubled.  
 = 1413.71

Force applied by calliper on each wheel

$$F_{cp} = P_{mc} \times A_{cp} \times \eta$$

$$= 7.57 \times 1413.71 \times 0.9$$

$$= 9631.60 \text{ N}$$

Total force applied,

$$F_{pt} = F_{cp} \times \mu$$

$$= 3852.64 \text{ N}$$

Torque generated,

$$T_g = F_{pt} \times \text{rotor radius}$$

$$= 3852.64 \times 0.15$$

$$= \mathbf{577.89 \text{ N-m} \dots\dots\text{torque generated}}$$

Required torque	Actual Torque
561.58 N-m	577.89 N-m

Stopping time (T)

$$T = \frac{v}{0.2g} = \frac{12 \times \frac{5}{18}}{0.2 \times 9.81} = 1.69 \text{ sec}$$

Stopping distance (S)

$$S = \frac{v^2}{2 \times g \times 0.4} = \frac{(15 \times \frac{5}{18})^2}{2 \times 9.81 \times 0.4} = 1.41 \text{ m}$$

**VI. RESULTS**

**A. STEERING SYSTEM**

- After the development a test was conducted on road so that we can measure the actual turning radius of the vehicle. We fix one point on road and took a turn. After measurement the turning radius was 2.5 meter which was close to calculated value with respect to design. But the results were not up to mark.
- So with little adjustment in rack travel tend to increase in angle of wheel, approximate to the desired value. After that we took a test again and the new turning radius was 2.480. Considering few compliance in system, the results were satisfying.



- Another most important factor that we took under consideration was the straight ahead recovery. During testing we took number of sharp turns making vehicle to go under G effect. Thus after the turn the vehicle use to tend to get straight at every time we use to turn, proving the design was up to the required condition.

**B.BRAKING SYSTEM**

- For braking system 2 main parameters that would show system functionality were stopping distance and wheel locking. For experimentation the vehicle was made run for its maximum speed of 15 km/hr. after that stopping distance that we got were 1.45 thus the results were approximate to the value that we got from design which was 1.41 m.

Parameter	Designed value	Actual value
Turning radius	2.4 m	2.480
Stopping distance	1.41 m	1.453 m

**VII. CONCLUSION**

Objective of this project is to make simple, compact, efficient and low cost harvester for small land holders. Our machine fulfils all the objectives. After working on this project following conclusion is drawn.

Rear wheel steered vehicle is very efficient and suitable for low speed harvester. It fulfils all the requirements. It gives low turning radius and smooth operation during change the bed. Force required to steer the vehicle is also reduced.

Disc brakes for front drive wheels prove best choice. Machine requires minimum effort for braking. Stopping distance and stopping time is also reduced. Machine qualifies all traffic rules. So this machine is became first choice for harvesting the field.

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