Design, Development and Manufacturing of Rear Wheel Steering System for Self Propelled Onion Harvesting Machine

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Abstract: *This Paper aims towards designing a steering system for a Self-Propelled Onion Harvesting Machine in order to achieve a small turning radius with minimal steering efforts. The steering system is an essential part of the vehicle as it allows the driver to turn the vehicle in required direction, which includes the steering wheel, steering gear box, pitman arm, drag link, tie rods, steering arms.*

In this paper rear wheel steering is being discussed instead of the convenient front wheel steering. Rear wheel steering is a technology on which research is still going on but its implementation in real life applications are limited. The attributes which make rear wheel steering effective in the agricultural sector vehicles are that it offers easy maneuverability at low speed and assists in achieving tight turning radius.

Keywords: Rear wheel steering, Agricultural Vehicles, Steering Geometry, Ackermann Geometry, Steering Ratio, Effort

1. INTRODUCTION

Automobile is a rapidly growing industry in the world, with the rapid growth and technology advancement it produces a huge scope of opportunities for the improvement in the designs and safety aspects of the vehicles. Steering system being one of the essential systems in any automobile vehicle, which helps driver to control the direction of vehicle, thus gives lots of opportunities for engineers to develop and implement steering systems with more steering comfort and improve the stability of the vehicle by modifying the steering designs and parameters.

The most convenient arrangement of steering in any vehicle is front wheel steering system operated by a steering wheel through steering rod and universal joint acting as connection between both of them.

The Steering system consists of various types of gearbox which act as a mechanical advantage in the steering system. The gearbox which are normally used in vehicles are rack and pinion, worm, worm wheel, ball and screw etc.

2. METHODOLOGY

The following methodology was adapted while designing the steering system:
➢ Defining Objectives for Harvester
➢ Literature Survey.
➢ Layout Selection
➢ Design And Analysis
➢ Manufacturing
➢ Testing And Validation of The Design

3. OBJECTIVES FOR HARVESTER

● To steer the rear wheel of the vehicle.
● To reduce the steering efforts of humans during vehicle operation.
● To achieve the turning radius below 3.5m.
● Driver Comfort

4. LITERATURE SURVEY

Prof. V.I. Pasare, et al. (2017), "Design of Steering & Braking System for Self Propelled Onion Harvester".
In this paper it has been discussed about designing the steering mechanism for agriculture machines. Agriculture machines have high strength and are robust, reliable, optimum and efficient. In order to get better turning radius and easy maneuverability during on field operation, a rack and pinion steering gearbox was used.

In this paper a front wheel steering system was designed for a self-propelled onion harvester for good field efficiency and easy maneuverability. In their work the designing and fabrication was decided by taking the customer demands and vehicle dimensions into consideration and were properly studied. Ackerman steering geometry with a rack and pinion gearbox was selected as it fulfilled all the customer demands and provided best efficiency and life to the system. An OEM steering gearbox of Maruti 800 was used which had a steering ratio of 18:1. The achieved results were that the turning radius was 2.859 m and had an Ackerman percentage of 70%. [1]

L. Strandberg, G. Tengstrand, H. Lanshammar (1982), "Danger, rear wheel steering".

In this paper they have discussed about Rear wheel steering which is most commonly used in forklifts and loaders. In their work they have discussed hazards of rear wheel steering and are illustrated with authentic accident case description and are explained through the analyses of vehicle dynamics. According to the paper the vehicle stability at every speed is required and the cornering stiffness coefficient of the rear wheels is larger than that of front wheels. The paper also states the risk of skidding of a vehicle is more in rear wheel steering. It was observed that if driver unknowingly over steers the vehicle, insufficient tire pressure or improper loading are few of causes for skidding. They had conducted the experiments on Fork lifts and tested forklifts at different lateral forces, various road conditions and different reaction time of the driver. They had concluded that using Rear wheel steering systems for high speed vehicle would promote accidents and have suggested using the front wheel steering system for normal cars which have high speed. [2]

Dr. V.K. Saini, et al. (2017), "Design Methodology of Steering System for All-Terrain Vehicles".

In this paper they have discussed that, the function of steering system is to steer the front wheels in response to driver's input. The paper states that the rack and pinion steering gearbox is widely used in passenger vehicles. In this paper a rack and pinion Ackerman steering mechanism was designed for an All-terrain Vehicle. Tata Nano steering column was used in their design and it is connected to Rack and Pinion Gearbox by a Universal Joint. In their work they had done market survey for all the required components and accordingly selected the appropriate component for the steering system. In their work they had kept the steering ratio of 5.44:1 and steering effort was 44.72N. [3]

Lukas K., et al. (2019), "Design of Rear Wheel Steering System of an Experimental Electric Vehicle".

In this paper they have discussed the Basics of steering system and also the four wheel steering kinematics of vehicle. In their work they had calculated rear wheel steering angle and then the concept of rear wheel steering was applied on an electric vehicle. It was concluded that for a non-autonomous vehicle it will improve driving performance in lower speed vehicles also vehicles with an autonomous steering system can use rear wheel steering system. [4]

Md. Danish Akhtar (2013), "Wheel Steering System".

In this paper, all basic information of the Steering system of vehicle and Design of 4-Wheel steering system has been discussed. In this paper different types of Steering system configuration and their advantages and limitation are stated. The paper concludes that the turning radius of a four wheel steering system is less than two wheel steering system by both analytical calculation and experimental method. It was also observed that by analytical calculation they found that there is 41.13% reduction in turning radius and by experimental method a reduction by 50.43% was observed. [5]

Rayappa Mahale et al. (2018), '' Design of Steering Gear System in Passenger Car: A Review".

In this paper they have discussed design procedure of steering gear system. They have explained the basics of Ackerman steering mechanism. They have started with material selection and chemical composition of material. They have explained various types of heat treatment process and calculation of gear profile to find out the dimension of gears. They have analyzed the designed parts on Ansys software to find out total deformation, equivalent stress and factor of safety. They have concluded that to improve steering of vehicle Ackerman steering geometry should be used and also the use of composite material increases the strength of rack & pinion and reduces the weight of system which helps to reduce gross weight of vehicle. [6]

Sarhan, Al-Katary, El-Awady (2009), "A study on agricultural tractors steering mechanism".

This paper mainly focuses on increasing the operational efficiency by introducing power hydraulic steering system in agricultural tractors in order to suit the conditions and potentials of Egyptian farmer. This increases the value of yield per feddan and increase the rates of the feddan production. By modifying and developing the modern technology, the strategic goals of the agricultural development are achieved in all agricultural operations and local environment. Hydraulic steering was designed by using a closed hydraulic circuit for the tractor and correspondingly laboratory experiments and statistical analysis for the data of the research were run. The modified design reduced the turning radius of the tractor from 5m to 1.5m and the friction between the front wheels and the steering equipment were reduced. The results obtained from the experiment consists of following points; 1) Steering angles were found by deriving some mathematical equations 2) The technical problems occurring repeatedly in the steering equipment's of the tractors were decreased 3) Decreased operation, maintain and used parts in the steering equipment's of tractors 4) The modification implemented can be suited for all agricultural operations in Egypt which improved the operational efficiency of the tractors. [7]

Arun Singh et. al. "Study of 4 Wheel Steering System to reduce Turning radius and Increase Stability".

In this the performance of four wheel steering vehicles is considered and Studied for lane changing maneuverability at different speeds for parking and turning. Rear wheels

in opposite direction assist the sharp turns and at higher speed all wheels turns in same direction which assists lane changing which results in the Stability of vehicles. Many modern cars uses Rack and pinion mechanism And by using this mechanism 4 wheel steering system was designed and tested.

As a result they got good maneuverability in driving, sharp turning and rapid lane changing, high speed straight line stability. Sharp turning is very useful for parking the vehicle in compact space, turning at 90 degrees road junction and for making U turns. [8]

V. Arvind et. al. "Optimizing the turning radius of a vehicle using symmetric four-wheel steering system".
In this paper, basic kinematics of both the conventional steering system and four-wheel steering system were discussed and along with it, few case studies were provided which did the comparison of the conventional steering and the change in turning radius of same vehicle in case four-wheel symmetry was used. The work done in paper mainly intensifies on the reduction of turning radius using the four-wheel steering system and thus uses the opposite phase of the four-wheel steering system configuration. The paper provided the kinematic relations which were used to calculate the turning radius for conventional steering and four-wheel steering. The paper introduced the term symmetric four-wheel steering system and the measurement of turning radius according to Indian standards. The case studies which were conducted by the author concluded that there was up to 35% reduction in the turning radius of vehicle after the implementation of the four-wheel steering system. [9]
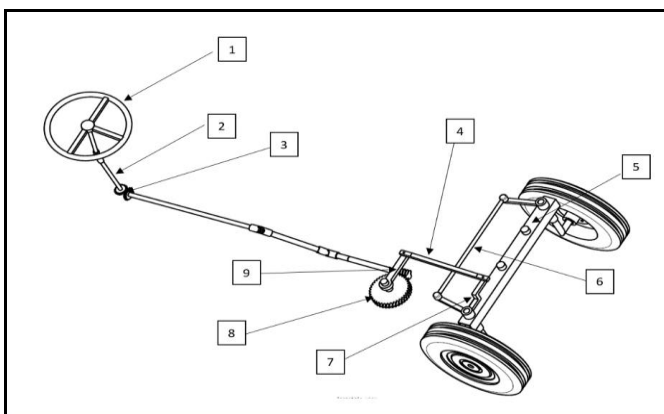
5. LAYOUT

Fig- 1 Layout of designed System

Table-1 List of Components of designed system

Component No.	Component Name
1	Steering Wheel
2	Steering Column
3	Bevel Gear
4	Drag link
5	Dead Axle
6	Tie Rod
7	Steering Arm
8	Worm Gearbox
9	Pitman Arm

6. DESIGN AND ANALYSIS

6.1 Material Selection
Material selection is the important aspect in any product design and selecting a proper material for the component reduces the overall cost of the system and also reduces the need of design optimization. The material selection process starts with a proper listing of the essential material properties required for a specific component. Material are then searched which depict the essential properties as listed above. A proper market survey is done for theses material in order to know the available material in market and thus reducing the efforts in manufacturing phase.

The materials are selected on the basis of the eases of availability of the material, the machineability of the material, the mechanical properties which are essential for the components and the material must be economical.
Thus after the market survey following were the material take for the designing and calculation:

Table-2 List of materials Used for the Components

Sr No.	Component	Material
1	Bevel Gear	Mild Steel
2	Worm and worm gear	EN9
3	Worm casing	Aluminum HE30
4	Shafts and column	EN8
5	Steering arm	C55
6	Drag link	EN8
7	Tie rod	EN8

6.2 Steering Effort Calculation
The following are the steering efforts calculation which were carried out by consideration of an average human hand force and the following data was obtained.
Force Required to Turn the Tire
$F_{Turn} = \mu \times m \times g = 1030.05 \text{ N}$

Moment at Kingpin $Mk = F \times h = 113305.5 \text{Nmm}$

Force required at Steering Arm $F = \frac{Mk}{L} = 515.025 \text{ N}$

Torque of Worm Gear

$T = F \times$ Length of Pitman Arm = 113.30 Nm

Torque of Steering Wheel = $T_{steering}$ = 9.4421 Nm

Steering Wheel Radius is 220mm

Steering Effort = $\dfrac{\text{Steering Wheel Torque}}{\text{Steering Wheel Radius}}$ =

42.91875 N

So 42.91N Force should be applied by the Driver to turn the vehicle.

6.3 Steering Column:

Steering wheel and Bevel gear are connected through steering column. The universal joint is used in between steering column for ergonomic point of view.

6.4 Steering Gear Box

One of the most important component in a steering system is the steering gear box. It is a combinations of gear which are used to transmit and magnify the steering efforts provided by the driver. The force is transmitted to the wheel via the steering linkages

There are various types of the steering gearboxes most commonly used is Rack and pinion because of the ease in designing. In our project a worm and worm wheel type steering gear box was used. A miter bevel gear pair was used to change the direction power and its output was connected to the steering gearbox which transmitted power to steering linkages and thus steering the wheels.

The parameters obtained for the gearboxes are as follows:

Bevel Gearbox

The Bevel Gear pair was designed by considering all the parameters like material Selection, human effort, force requires to turn the vehicle and Factor of Safety. And the following parameters were calculated.

By our requirement and Space availability, we considered to use miter gear pair to turn the direction of effort.

➢ Number of teeth on pinion, Gear = 20
➢ Module= 3mm
➢ Radius of pinion = 60mm
➢ Radius of gear = 63mm
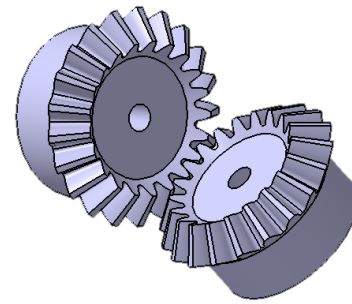➢ Face width = 15mm
➢ Pitch cone distance = 43.5m

Fig- 2 CAD Model of Bevel Gears

Worm Gearbox

The Worm gearbox was designed to have the output torque which will be more than the required to turn the vehicle. And by considering the parameters of material selection the gearbox was designed. And the following parameters were calculated.

➢ Module = 5mm
➢ Speed ratio = 12.5: 1
➢ Number of Starts = 3
➢ Number of teeth on gear = 37.5 = 38
➢ Diametral Quotient = 10
➢ Designation of worm and worm gear pair- (Zw/Zg/q/m):- 3/38/10/5
➢ Diameter of worm = 50mm
➢ Diameter of gear = 190mm
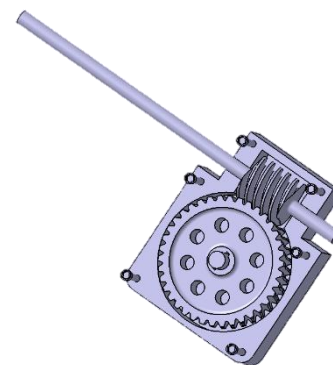➢ Face width = 36.5mm
➢ Length of worm = 82.62mm

Fig- 3 CAD Model of Worm Gear pair

6.5 Design of Pitman Arm and Steering Arm

The pitman arm is the output arm from the steering gearbox which drives the steering Ackermann geometry. The max force in the steering is experienced by the following part. It basically drives the Ackerman and thus requires max torque to be produced. The pitman arm is thus designed by taking consideration of all factors like max force need to be developed to steer, max load on vehicle, economical to produced etc.

Steering arm are the arms which are necessary to drive the four bar Ackerman system the steering arms are the once which are connected to stub axles and thus they are the once which actually steer the wheels. The steering arms were designed by selecting a proper material and also by managing the budget and maintaining the FOS of the system. The steering arm were designed by taking consideration the friction force which the wheel need to overcome along with the normal force which would be on the wheels also the tire and soil relation was studied and accordingly the steering forces were calculated.

Force required to turn wheel by Pitman Arm
As the force required to turn the tire was 2600N, so to turn two wheels the force should be double of that,
So Force = 2600 × 2 = 5200 N
Required Moment transfer from pitman arm to steering arm is 10400 N-mm
Length of Arm L = 220 mm
Assuming the Width (b) = 35 mm, Thickness d = 25 mm,
(By performing the iterations)
Maximum Bending Stress by Flexural Formula

$$\frac{M}{I} = \frac{\sigma_b}{y}$$

$$\sigma_b = 6.45 \ N/mm^2$$

The material Selected is having Syt=350Mpa and Considering Factor of Safety of 4

$$\sigma_b < \sigma_t$$

Therefore, Design is Safe

6.6 Design of Tie rods and Drag link

Tie rods is the basic linkage between the steering arms which enables to steer the vehicle by connecting the steering arms and thus steering both the wheels. The tie rod is the component which is supposed to fail first in the steering system in case of any failure. The steering tie rods were thus designed in such a way that the failure of tie rod would occur first and also the tie rod are designed in such a manner that it would be easily changeable and easy for maintenance. The Tie rod and steering arms are connected by the ball joint in order to have a smooth and easy turning.

Drag link is the linkage drive which connects the pitman arm and the steering arm and is the link which enables to steer the vehicle. The Drag link is designed in such a way that in can withstand the maximum amount of the tension and compressive force and can work without any failure. The drag link the material is selected in such a way that it has high strength and is light in weight. Just like the tie rods is similarly connected by a pair of ball joints.

Drag Link
Length = 500mm (By performing the iterations)

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} = 92.17 \ KN$$

Tie Rod
Length = 660mm (By performing the iterations)

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} = 71.18 \ KN$$

6.7 Steering Ratio Calculation

- The Steering ratio x: y implies that you have turn the steering wheel x degree(s) in order for wheel(s) to turn tires by y degree(s).
- A higher steering ratio means that you have to turn the steering wheel more so as to get the wheels turning though it will be easier to turn the steering wheel.

Lock to lock position of Pitman Arm is restricted to 104.76^0 and Gear ratio of worm is 12.5:1

Therefore rotation of worm gear is $= \frac{104.76}{360} \times 12.5 = 3.63$ rotation

Lock to lock position of Tire is 107.4^0

$$\text{Steering Ratio} = \frac{\text{Total Rotation of Steering Wheel}}{\text{Total Rotation of Tyre}} = 12.16$$

6.8 Ackerman Percentage

Basically Ackerman percentage decide 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 tire.
100% Ackerman is ideal turning condition of vehicle. If reduce it causes understeering and if increased then over steer is caused. Disadvantages come with the how much away you are from ideal conditions.
Inner Wheel Angle $= \theta_i = 63^0$.
Outer Wheel Angle $= \theta_o = 44.4^0$

$$\text{Ackerman} = \tan^{-1}\left(\frac{\text{Wheelbase}}{\frac{\text{Wheelbase}}{\tan(\theta_o)} - \text{Wheel track}}\right) = 63.78$$

$$\text{Ackerman\%} = \frac{\theta_i}{\text{Ackerman}} = 98.76\%$$

Table-3 Specifications of designed system

Type of steering system	Ackerman
Steering type	Rear wheel
Steering Gearbox	Worm & Worm Wheel
Turning radius	3m
Ackerman percentage	98.76%
Steering effort	42.91N
Steering ratio	12.16:1

7. CAD & ANALYSIS OF THE COMPONENTS

The designing the component once completed then the preparation of the CAD model starts .The CAD models were created using Catia V5 and PTC Creo Parametric software. The CAD were produced exactly the way the components were designed and were expected to manufacture. Analysis of the CAD components was carried out by using Ansys Workbench 18.1 software. The Analysis was done by considering all the forces which the part would experience while operating in dynamic conditions. The following results were obtained from the analysis
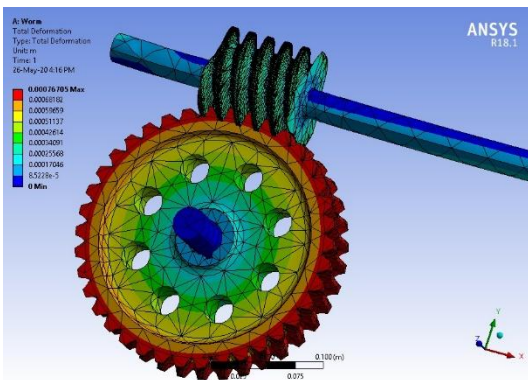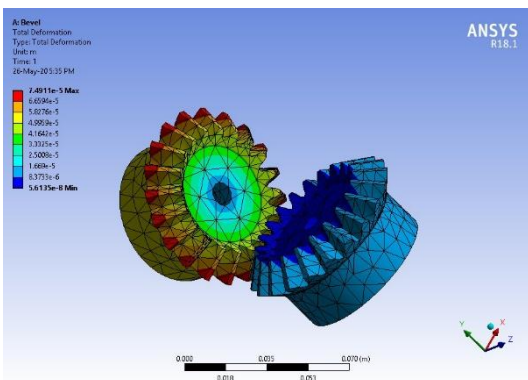

Fig- 4 Total Deformation of Worm Gear

Fig- 5 Total Deformation of Bevel Gears

Table-4 Analysis result of all parts

Part	Max. Equivalent Stress	Total Deformation (mm)
Bevel Gear	132.91 MPa	0.0749 mm
Worm Gear	295.16 MPa	0.7670 mm
Pitman Arm	19.516 MPa	0.1249 mm
Steering Arm Left	87.251 MPa	0.4586 mm
Steering Arm Right	273 MPa	0.4709 mm

The Results of the analysis were then compared with the actual theoretical calculations and thus the designed were ensure safe for manufacturing.

8. MANUFACTURING

The designed CAD components were properly drafted and a proper drawings were prepared of each components. A market survey was then done to find various manufactures for manufacturing the components. The parts which were available as OEM parts were directly bought and all other components were manufactured.

Fig- 6 Bevel Gears

Fig- 7 Pitman Arm

Fig- 8 Worm Gearbox

Fig- 9 Steering arms

Fig- 10 Bearings

Fig- 11 Ball Joints

9. FUTURE SCOPE

- The Rear wheel Steering System Can be Used in low speed vehicles which requires high maneuverability and low turning Radius
- The Rear wheel steering can be implemented by using it with the assistance of power steering.
- Implementation of the rear wheel steering in conventional vehicles by assisting it with various electronic sensors and circuitries.
- Four-wheel steering is an emerging steering system and inspired by the rear wheel steering.

10. CONCLUSIONS

- Rear wheel steering is a highly discussed topic in the development of vehicles. It will improve the driving performance especially in Low Speed vehicles.
- It is concluded that the design easily achieves the objectives which were set.
- Due to implementation of the rear wheel steering the maneuverability of the machine has increased significantly along with achieving a very tight turning radius which is very essential in agricultural working conditions.
- It is also concluded that the turning radius of the vehicle can be further reduced near to its wheel base by implementation of turn-wheel locking.

ACKNOWLEDGEMENT

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