Design of powertrain and steering system for six wheels agricultural transporter

Desrial, RPA Setiawan, A Sutejo, IM Edris, MNA Fauri and RA Faris

Department of Agricultural Engineering and Biosystem, Faculty of Agricultural Engineering and Technology, IPB University, Jl. Raya Dramaga Kampus IPB Dramaga Bogor 16680 West Java, Indonesia.

E-mail: desrial_ipb@yahoo.com

Abstract. Transportation activity of agriculture’s production inputs and products from farm to processing house or storage house is generally carried out on poor road condition. Therefore, a special vehicle that can transport the products and able to pass agricultural farm easily is needed. The objective of this research was to design the powertrain and turning system of six wheels agricultural transporter. The design criteria of this vehicle was as follow: load capacity 750 kg and vehicle’s dimension fits to road class III criteria. The main components of powertrain system and turning mechanism were chassis, engine, gearbox, chain, sprocket, shaft, disc brake and tire wheels. The method of this research followed the common procedure of machine design process and continued to manufacturing and testing. The performance test showed that maximum forward speed without carrying load was 7.8 km/h and with maximum load was 6.6 km/h. The smallest 180° turning radius was 3.5 m at engine speed of 3500 rpm which occurred when vehicle without carrying load.

1. Introduction
In order to distribute agricultural products from temporary collecting point to processing or storage house, the roads are commonly not in good condition. Besides that, the distance from temporary collecting point to processing house is quite far, so it needs special vehicle that can pass that poor roads with high load capacity in order to optimize the distribution.

This research is also part of agricultural transporter development which is also a continuation of Fastrex CT-02 transporter that had been done before [1]. Fastrex CT-02 used track wheel, the traction is good so it can be operated in every fields condition. However, the limitation of track wheel type is low speed, heavy weight and low payload capacity. In addition, track wheels cannot be used on public roads such as asphalt and concrete. Therefore, the purpose of this study was to design a transmission system and turning mechanism for six wheels transporter to have better traffic ability with lighter weight and can be operated both on agricultural land and on public roads.

2. Method
This research was conducted at Laboratory of Siswadhi Soepardjo, Department of Agricultural Engineering and Biosystem, Faculty of Agricultural Engineering and Technology, IPB University. The method used in this research was common machine design process standard performance test method
The research was consisted of formulation of design criteria, design analysis, design evaluation, simulation, engineering drawing, manufacturing and performance test.

2.1. Design Criteria
This vehicle was designed to operate on soft, rocky and compacted-agricultural roads. The slope that can be passed by this vehicle was designed at $20^\circ$. The maximum load capacity was 750 kg with a maximum carrying bucket volume was 1.2 m$^3$. The power transmission system from engine to 6 wheels drive used combination of pulley-belt, Hydro Static Transmission (HST) gearbox and sprocket-chain with designed maximum forward speed was 8 kmh$^{-1}$ on flat road. Turning system used skid-steering system assisted with turning clutch and braking system [3]. The maximum dimension and total weight of the vehicle must not exceed the maximum dimension and total weight of class III road vehicle [4] i.e. maximum length 9000 mm, maximum width 2500 mm, maximum height 3500 mm and maximum weight 8 ton. The vehicle ground pressure must not also exceed the soil bearing capacity 100 kPa.

2.2. Design Analysis
Each components of the design was analyzed to check whether the design was fit with the criteria and also to confirm whether the design was safe to be used. This analysis comprised of functional analysis, and structural analysis. Functional analysis was conducted to determine the main function of the vehicle and to find out the functions of each main components to support the main function. Structural analysis was conducted to find out the shape and dimension of the vehicle starting from the main component to the whole parts of the vehicle. The analysis was also done for technical parameters in the vehicle including weight balance analysis, center of gravity analysis, maximum slope analysis, power transmission analysis, forward speed analysis, power requirement analysis, wheel shaft diameter analysis, and ground pressure analysis.

2.3. Performance Test
Working performance parameters tested in this research were vehicle speed, wheel slip and turning radius [5]. Speed and slip testing were carried out on four track and roads type i.e. straight track on asphalt road, straight track on grassy soil road, straight track on loose soil road and sloping (upward) track on asphalt road with two load treatments namely without load and maximum load. The soil carrying capacity was measured by using penetrometer type SR2 [6]. The parameters of performance test of transporter on a sloping road was done similarly with the parameters of transporter on a straight road. Turning radius was tested under condition of without load and maximum load. Test of turning radius was done by controlling the turning lever in full position without additional lever treatment by operator as well as without braking when turning.

3. Result and Discussion

3.1. The design of vehicle

3.1.1. Main frame (Chassis). The main frame of this vehicle was designed by using U shape steel with size of 100 x 50 x 5 mm type G4051 class S30C. Since this vehicle will be operated on road class III, therefore the dimension of the main frame was designed not to exceed the maximum limit of vehicle dimension of road class III. Based on the predetermined vehicle’s components, the dimension of the vehicle were 2648.36 mm (length), 1571.92 mm (width) and 2039.82 mm (height) (figure 1). The total weight of the vehicle in condition without loads and without operator was 669.9 kg.
Based on the force balance analysis, it can be concluded that the maximum allowable slope for vehicle to pass was $23.4^\circ$ thus road with slope $20^\circ$ still can be passed. The maximum slope for lateral plane with empty load was $44.6^\circ$ and the maximum slope for lateral plane with maximum load was $40^\circ$.

3.1.2. Powertrain system.

The engine used in this vehicle was 9.50 hp or 6.98 kW diesel engine. The transmission used combination of pulley-belt, gearbox and chain-sprocket. The gearbox was hydrostatic transmission (HST) type [7]. The advantage of HST gearbox type is ease operation as the transmission is done continuously by only change the position of acceleration lever to adjust the speed. This gearbox also functions as a steer to turn the vehicle. This vehicle turns by adjusting the left or right clutch so the vehicle turns in the desired direction. If it is difficult to turn because of heavy loads, then a separate brake is used on the left wheel and the right wheel so that the vehicle can turn perfectly. The highest transmission ratio at the highest acceleration was 24:1. Transmission system scheme of this vehicle is seen on figure 2.

![Figure 2. The transmission system of the vehicle.](image)
Pulley-belt was used to transmit power from engine to gearbox. In order to minimize slip, same diameter of pulley was used. The engine rotational speed during operation was set at 3500 rpm. Thus the rotation speed at the gearbox input shaft was 3500 rpm. Based on the belt calculation analysis, the belt needed was belt type C no. 47, single belt, with length of 1194 mm.

The speed reduction of HST gearbox was 52:1 for low speed, 30:1 for medium speed, 24:1 for maximum speed and 26:1 for reverse speed. Thus, the rotation speed at gearbox output shaft was 67.307 rpm at low speed, 116.667 rpm at medium speed, 150 rpm at maximum speed and 134.615 rpm at reverse speed.

Meanwhile, the chain-sprocket was used to transmit power from gearbox output shaft to wheel shaft. The ratio of teeth number in the sprocket was 1:2. Based on the sprocket calculation analysis, chain number 60, double chain with 54 teeth were selected. Sprocket with 19 teeth was selected to be used at the gearbox output shaft, while sprocket with 38 teeth was selected to be used at wheel shaft.

### 3.1.3. Vehicle Speed

Wheel diameter was adjusted to obtain required torque and forward speed. The wheel shaft used in this vehicle had diameter 40 mm. The forward speed of the vehicle when carrying maximum load and without load was adjusted with available power of the engine for flat road and sloping road. When carrying maximum load, the forward speed at flat road was 1.90 ms\(^{-1}\) (6.8 kmh\(^{-1}\)) and at sloping road was 0.62 ms\(^{-1}\) (2.2 kmh\(^{-1}\)). When without load, the forward speed at flat road was 2.18 ms\(^{-1}\) (7.85 kmh\(^{-1}\)).

### 3.2. Performance test

#### 3.2.1. Wheel slip

The maximum speed on asphalt road (asphalt), grassy soil road (grassy), loose soil (loose) and 5° constant sloping road (sloping) was 1.58 ms\(^{-1}\), 1.52 ms\(^{-1}\), 1.51 ms\(^{-1}\) and 1.2 ms\(^{-1}\), respectively. The left and right wheel slip at a condition without load (0L) and carrying maximum load (ML) are shown in figure 3 and 4.

![Figure 3. Slip magnitude on the left wheel.](image-url)
Based on the result, the right wheel had higher average slip compared with the left wheel due to the location of vehicle’s center gravity was slightly more to the right side. Compared with testing on asphalt road, testing on grassy soil road where the condition was not too flat and slightly slippery reduced the wheel rotation and wheel speed either without load or carrying maximum load. Furthermore, on loose soil where the soil penetration was low, a heavier load caused higher slip which then limited the wheel rotation and reduced speed.

3.2.2. Turning radius. The turning radius performance result of the vehicle is shown in Table 1. The highest turning radius with maximum speed and load was 12.2 m. The smallest turning radius without load was 3.5 m. Those number showed that the turning radius when carrying load was quite high because the brake under maximum load couldn’t work properly. Therefore, a gradual back and forth turning motion should be done to make smaller turning radius.

### Table 1. Turning radius result

| Turning radius (m) without load | Right | Med | High | Average |
|-------------------------------|-------|-----|------|---------|
| Right                         | 3.81  | 3.53| 3.17 | 3.50    |
| Left                          | 3.95  | 3.84| 4.55 | 4.11    |
| Turning radius (m) with maximum load | Right | Med | High | Average |
| Right                         | 9.86  | 12.44 | 11.32 | 11.21 |
| Left                          | 11.95 | 12.08 | 12.57 | 12.20 |

4. Conclusion

Six wheels transporter had been successfully developed and performance test on slip and turning radius had been conducted. Based on the result of performance test, it can be concluded that power transmission system fulfilled the design criteria. By using diesel engine 9.5 hp, the maximum forward speed that could be achieved was 2.18 ms\(^{-1}\) at a condition without load and 1.89 ms\(^{-1}\) at a condition of maximum load 750 kg. The power transmission designed in this vehicle showed good design as it caused slip less than 8%. The turning radius when carrying maximum load was 12.2 m and turning radius without load was 4.1 m. In order to improve the performance of turning radius when carrying maximum load, it is
suggested to improve the brake performance at each wheels shaft. This six wheels transporter is expected can improve the agricultural products distribution efficiency.

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