

Design, fabrication and performance evaluation of tractor drawn trailer for PV powered rice threshing machine

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Abstract - A tractor drawn trailer was designed and fabricated for solar photovoltaic rice threshing machine, using local available materials. It was designed for easy maintenance and to withstand rough site conditions. Its performance was evaluated by mounting the calculated load of 602kg consisting of an inverter, four (4) batteries of capacity 100Ah each, charge 20A controller, cables, two (2) solar modules, and a Vortex rice fan thresher. Tractor constant speed at the time of the experiment was 4km/h. The drawbar pull was 17.71kN, the trailer wheel diameter as design was 25.5cm. The wheel torque was determined to be 0.226KN. The power available at the drawbar was determined to be 70.84kW; and the power required to pull the tractor drawn solar photovoltaic system for rice threshing machine was 1181.4kW. The tractive coefficient was 0.0294, gross tractive coefficient was 17.71kN. Soil reaction was calculated to be 2.8 the tractive efficiency was 4.797 and engine torque 80.0NM.

Key Words: Design, Tractor, Drawn, Trailer, Photovoltaic, System.

1.0 INTRODUCTION

In developing countries, the bulk of the population lives in the rural areas, often in widely scattered communities with poor transport systems; with animal drawn cart, human drawn cart, single truck etc., as their only means of haulage. This has high drudgery and time consuming. Transport and means of easy haulage is therefore very important in the rural community than in the urban where activities and services are more accessible. The major transport need of the rural population is about 70% (Adeoti et al. 1989). Energy remains an important input for sustainable development and economic growth of any country. Electrical energy is proven to be the most convenient form of energy in both rural and urban areas and its availability promotes rapid economic and industrial growth. Electrical grids remain the only means of carrying electric energy from one place to another. The cost of grid electricity is so high for rural inhabitants especially the farmers. The use of solar micro grid in rural areas may not solve the electricity problem in remote farm locations. Other forms of transportation may be very expensive, except animal or human drawn- cart which may be too slow and highly

stressful. The use of human effort for haulage is so stressful and is used for haulage over short distance as (up to a maximum of 8km). The preferred choice has been the combination of Agricultural tractor and two wheeled trailer, (Jim et al 1999). The choice of trailer depends on its application. Solar energy is proven to be the best alternative for on-farm post-harvest operations such as cooling, milling, threshing, pumping, etc., because of lack of electric grid in such rural locations (Aju et al 2016). Animal power is the next stage after manpower in the progression to basic vehicles. A trailer is generally an unpowered vehicle towed by a powered vehicle. It is commonly used for the transportation of goods and materials. A tractor drawn trailer was designed, and fabricated to carry a load of 602kg. Its performance was evaluated to see areas of failure.

1.1 AIMS AND OBJECTIVES

The objectives of these studies are to:

1. Design a trailer for Photovoltaic Powered System for Rice Threshing Machine.
2. Fabricate the Designed trailer to carry the Photovoltaic system for rice Machine.
3. Test the performance of the tractor drawn trailer for Photovoltaic system for rice Machine.

2.0 MATERIALS AND METHOD

Mild steel was selected for the construction of this trailer. Properties of such as rigidity, weldability, availability and affordability were considered in the selection of materials. Inflated Rubber tires were selected for the tractor drawn trailer for rice threshing machine. The design considerations and calculation is as shown below.

2.1 Design consideration of Trailer

The design considerations of the trailer were:

1. Load bearing capacity and weight distribution of the trailer taking into consideration the weight of the

thresher, electric motor, batteries, inverter, and the modules;

2. Availability of materials.
3. Rigidity of the machine.
4. Ease of maintenance.
5. Structural stability of the trailer considering the terrain of operation.
6. Hitch coupler selection Axle Selection and Axle placement

2.2 Design of Trailer Axle Shaft

The trailer axle shaft did not directly carry any load. The loads were carried by the two wheels of the trailer. Therefore there was no bending moment on the shaft ($M_b = 0$).

There was torsional moment on the shaft at the wheels of the trailer.

The torsional moment (M_T) acting on the shaft was determined from equation 1.

$$M_T = Mar \dots\dots\dots (1)$$

Where:

M is weight acting on the wheels of the trailer,

a is the acceleration due to gravity.

r is the radius of the wheel = 0.3m.

The diameter of the trailer axle shaft was determined using the ASME equation (Hall et al, 1961) as in equation 2.

$$d^3 = \frac{16}{\pi S_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \dots\dots\dots (2)$$

d = Shaft diameter, m

K_b = combine shock and fatigue factor applied to bending moment = 1.5

K_t = combine shock and fatigue factor applied to torsional moment = 1.5

M_b is maximum bending moment, Nm

M_T = torsional moment, Nm

S_s = allowable stress for commercial steel shaft under torsional loading $S_s = 55 \times 10^6 \text{N/m}^2$

Since $M_b = 0$, equation 2 reduces to equation 3

$$d^3 = \frac{16}{\pi S_s} \sqrt{(K_t M_t)^2} \dots\dots\dots (3)$$

2.3 Check for lateral rigidity of Trailer Axle Shaft

Design of shaft for lateral rigidity is to enhance accurate trailer performance, satisfactory gear tooth action and shaft alignment. The design of shaft for the lateral rigidity is based on the permissible angle of twist. The shaft is considered rigid if the amount of twist angle is between $0.3^\circ/\text{m}$ to $3^\circ/\text{m}$ for machine with line shaft. The angle of twist was determined from equation 4.

$$\theta = \frac{584 M_T L}{G d^4} \text{ For solid shaft (Bhandari, 1994) } \dots\dots\dots (4)$$

Where: L is shaft length, m,

G is modulus of rigidity which is Modulus of rigidity for steel = $80 \times 10^9 \text{N/m}^2$.

2.4 Design of Bearing

The approximate rating or service life of ball or roller bearing is determined by the equation 5 (Khurmi and Gupta 2008).

$$L = \left(\frac{C}{W}\right)^k \times 10^6 \text{ rev} \dots\dots\dots (5)$$

Where:- L is fatigue or rating life or equivalent load

C is basic load rating or dynamic carrying capacity

W is dynamic equivalent radial load

The relationship between the life in revolutions (L) and the life in working hours (L_H) is given by equation 6

$$L_H = \frac{L}{60 N_B} \dots\dots\dots (6)$$

Where: N_B is speed in revolutions, assuming shaft speed (N_s) is equal to bearing speed (N_b), L_H is usually 40,000 to 60,000 hours (Khurmi and Gupta 2008).

$$N_B = \frac{P \times 60}{2\pi M_T} \dots\dots\dots (7)$$

Where P is power

The dynamic capacity, C was determined from equation 8 (Khurmi and Gupta 2008).

$$C = W \left(\frac{L}{10^6}\right)^{1/k} \dots\dots\dots (8)$$

Where:- K is constant = 3 for ball bearings (Khurmi and Gupta 2008), The dynamic equivalent radial load (W) was determined from equation 9.

$$W = XVW_R + YW_A \dots\dots\dots(9)$$

(Khurmi and Gupta 2008)

Where:- W_R is radial load

W_A is thrust load = 0

X is radial factor = 1

Y is thrust factor = 1

V is rotational factor =1

The bearing life L_B in years was determined from equation 10.

$$L_B = \frac{L_H}{W_n} \dots\dots\dots(10)$$

Where: - W_n is the working hour of the trailer.

Table 1 Summary of designed shaft parameters

| Parameter | Symbol | Unit | Value | Source |
|--|------------|------------------|----------------------|-------------------------------|
| Diameter | d | mm | 50.0 | designed |
| Torsional moment | M_t | Nm | 903.0 | designed |
| Combine shock and fatigue factor applied to M_t | K_s | - | 1.5 | hall etal,1961 |
| Allowable stress for shaft without key way under torsion | S_s | N/m ² | 55 x10 ⁶ | sga-site.yolasite.com/.../... |
| Length of shaft | L | m | 0.11 | designed |
| Modulus of rigidity | G | N/m ² | 80 x 10 ⁹ | Khurmi & Gupta 2008 |
| Shaft twist angle | θ | degree | 0.12° | designed |
| Twist angle/length of shaft | θ/L | °/m | 1.1 | designed |

Table 2 summary of designed bearing parameters

| Parameter | Symbol | Value | Unit | Source |
|--------------------------------|--------|-----------------------|-------|----------------------|
| Rating life | L | 2247 x10 ⁶ | rev | designed |
| Speed of bearing | N_z | 749 | rpm | designed |
| Bearing life | L_z | 50000 | h | designed |
| Power | P | 70.84 | kW | designed |
| Dynamic capacity | C | 41.9 | kN | designed |
| Ball bearing constant | K | 3 | | Khurmi & Gupta, 2008 |
| Dynamic equivalent Radial Load | W | 3010 | N | designed |
| Bearing life | L_z | 34.7 | years | designed |

2.5 Design of Drawbar of the Trailer

1. The drawbar should not exceed a maximum height of 508mm from the ground level and it must be horizontal to the ground.
2. The drawbar should extend at least 457.2mm behind the center of the rear axle and have a sturdy 63.5mm hitching loop or clevis attached. The hook should be able to move freely in the hitch hole or clevis. The height of the clevis type hitches was measured from the point at which the clevis attaches to the tractor.
3. Nothing should touch the sled hookup chain and all drawbar hitches must be rigid.
4. The Drawbar should be secured in all directions, with a hitch opening in the drawbar that is up to 63.5mm diameter.
5. The length of the drawbar should be set to allow the tractor to make a sharp turn without the rear tires fouling the trailer.

Assuming there are no losses in forward motion due to wheel slip and drawbar pull due to rolling resistance, and assuming all the power from the engine is available at the drawbar to be used in the pulling of the trailer. The travel speed of the tractor will be equal to the travel speed of the trailed cart. Equations 11 – 20 were obtained, applied from (Macmillian, R. H. 2002).

The power available at the drawbar (Q_d) was determined from equation 11.

$$Q_d = PV \quad \dots\dots\dots (11)$$

Where;- P is the drawbar pull (KN)
 V is the travel speed in Km/hr
 Engine power (Q_e) was determined from equation 12.

$$Q_e = 2\pi T_e N_e \quad \dots\dots\dots (12)$$

Where:

T_e is the engine torque

N_e is the speed

Π is a constant

The tractive coefficient (ψ) was determined from equation 13.

$$\psi = \frac{\text{drawbar pull}}{\text{weight on driving wheels}} \quad \dots\dots\dots (13)$$

The gross tractive coefficient (ψ') was determined from equation 14.

$$\psi' = \frac{\text{tractive force}}{\text{weight on wheel}} \quad \dots\dots\dots (14)$$

The tractive force (T_f) was determined from equation 15

$$T_f = \psi' \times W_w \quad \dots\dots\dots (15)$$

Where:

ψ' is the gross tractive coefficient

W_w is the weight on wheel.

The Soil reaction (H) was determined from equation 16.

$$H = \frac{2qT_e}{D} \quad \dots\dots\dots (16)$$

Where:- q is the transmission ratio

T_e is the engine torque

D is the wheel diameter.

Wheel torque (T_w) was determined from equation 17.

$$T_w = q T_e \quad \dots\dots\dots (17)$$

The Tractive efficiency (η_t) was determined from equation 18

$$\eta_t = \frac{PV}{2\pi T_w N_w} \quad \dots\dots\dots (18)$$

Where:- P is the drawbar pull

V is the travel speed

N_w is the wheel speed

T_w = wheel torque

Tractive force (T_f) was determined from equation 19

$$P = T_f - R \quad \dots\dots\dots (19)$$

Where R is the rolling resistance which was assumed to be negligible therefore

$$P = T_f \quad \dots\dots\dots (20)$$

In (b) above rolling resistance was assumed neglected.

2.6 Construction of the Trailer

A u channel bar of dimension 100mm x 100mm x 100mm was cut with power saw to the length of 2360mm x two (2) pieces and to the length of 800mm x two (2) pieces. The four bars were welded permanently to form a rectangular frame part No. 5. The u channel bar was again cut to two (2) pieces of 780mm lengths and welded to the frame as reinforcement. Two metal sheets of dimension 2mm thickness, 544mm x 340mm and another two metal sheets of the same thickness and dimension 780mm x 340mm were welded together to form a metallic box called inverter and battery housing at the front end part No. 4. A 30mm x 30mm angle iron of the same dimension was cut and welded together to form the cover. The cover has a wire mesh at the top. The rectangular frame part No. 5 was welded to two wedges, one wedge at each side welded to a hollowed pipe of dimension 128mm x Ø80mm. Shaft of 50mm diameter and length 1080mm was connected to two ground wheels of diameter 360mm. This was connected through the wheel hub system containing well designed bearings to allow smooth and easy rotation. The ground wheels were fitted with well inflated tyres part No. 12 to maintain adequate traction with the soil. Two pieces of 60mm x 60mm x 518mm angle iron bar were cut and bridged with an iron rod of diameter 20mm and length 800mm to form the support stand part No. 3 at the front end. The support stand was pivoted to enable it be hanged when the trailer would be on motion. Welded to the main frame part No. 5 was a 900mm x Ø60mm hollowed pipe with internal diameter of 40mm and a ring made up of rod of diameter 36mm having outside diameter of 115mm and internal diameter of 56mm to form a rigid drawbar part No. 2. A 30mm x 30mm angle iron bar was cut into two (2) pieces of the length of 2160mm and into two (2) pieces of length 1660mm. These were welded together using arc

welding machine to form a rectangular module sitting part No. 7. The module frame was suspended at the height of 1830mm by four (4) pieces of 30mm x 30mm angle iron cut and welded to the trailer frame. A metal plate of dimensions 2mm thickness, 800mm x 846mm was cut and welded to the trailer frame at the rear end to form the operator’s platform (floor) part No. 11. The thresher was rested on the frame, fixed firmly with bolts and nuts. Figure 1 is the side view of the tractor drawn trailer for rice threshing machine.

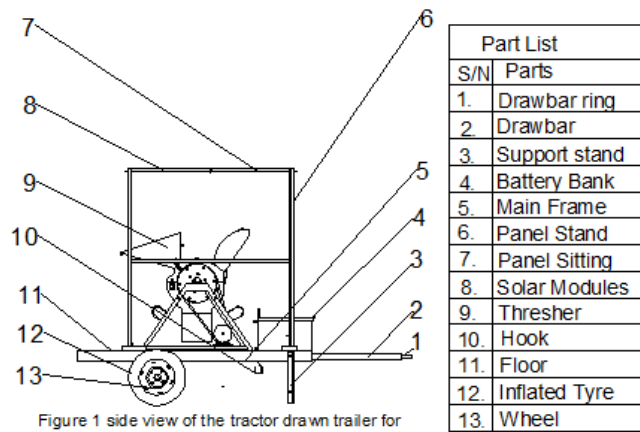


Figure 1 side view of the tractor drawn trailer for photovoltaic powered rice threshing machine

2.7 Description of the Trailer

The roof of the trailer is the solar module. The trailer has two - wheels connected by a round shaft. It has a drawbar from which it is coupled to the drawbar of the tractor through a coupling ring. It is incorporated a flat metal plate (floor) to enable the operator stand on during threshing operation.

2.8 Description of the Solar Photovoltaic System

The solar PVC system consists mainly of solar modules, a charge controller, a battery bank and an inverter. The modules receive and convert the insolation upon them to direct current electricity. Two (2) solar modules of the capacity 200W @ 24V each were connected in parallel; the two modules were connected to a 20A charge controller to prevent over charging and to prolong the life of the connected batteries. The charge controller was connected to a battery bank of four (4) batteries each of 100Ah capacity all connected in series. The batteries were connected to a 3.5kVA @ 48V inverter, which converts the stored d.c charges from the batteries to a.c. electricity. The a.c electricity from inverter powers the 750W electric motor that drives the threshing drum of the thresher for its threshing operation..

2.9 Performance evaluation of Trailer for PV System for Rice Threshing Machine

2.9.1 Determination and analysis of tractive force

The 2- wheeled tractor drawn trailer for rice threshing machine was pulled by a tractor. The ideal engine speed, engine torque, drawbar-pull, travel speed and the gear ratios at different speed were obtained and applied in calculating the tractive parameters. Table 3 is the summary of determined tractive parameters.

Table 3 summaries of determined tractive Parameters

| Parameter | Symbol | Value |
|-------------------------------|----------|----------|
| Engine power | Q_e | 1181.4KN |
| Drawbar power | Q_d | 70.84kw |
| Drawbar pull | P | 17.71KN |
| Tractive force | T_f | 17.71KN |
| Weight of the machine | W | 602.07Kg |
| Wheel diameter of the trailer | d | 25.5cm |
| Wheel torque | T_w | 0.226KNM |
| Tractive efficiency | η_t | 4.797 |
| Tractive coefficient | ψ | 0.0294 |
| Gross tractive coefficient | ψ' | 17.71KN |
| Travel speed of tractor | V | 4KM/h |

3.0 RESULT

A 2 - wheeled tractor-drawn trailer for photovoltaic system for rice threshing machine was designed and fabricated using local raw materials having length of about 326cm, and width of about 120cm, height of about 235cm with a clearance of 51cm from the ground level. Test conducted on this trailer indicates that the trailer though rigidly fabricated was able to carry the designed loading capacity consisting of an inverter, four (4) batteries of capacity 100Ah each, charge 20A controller, cables, four (4) solar modules, and a Votex rice fan thresher. It was able to withstand rough terrain on farm lands the draw bar point needed more reinforcement.

4.0 DISCUSSION AND CONCLUSIONS

Table 3 shows the summary of determined tractive parameters and other parameters of the trailer; Tractor constant speed at the time of the experiment was 4km/h. the drawbar pull was 17.71kN, total weight of the machine was 602Kg. the trailer wheel diameter as design was 25.5cm. The wheel torque was determined to be 0.226KN. The power available at the drawbar was determined to be 70.84kW; and the power required to pull the tractor drawn solar photovoltaic system for rice threshing machine was 1181.4kW. The tractive coefficient was 0.0294, gross tractive coefficient was 17.71kN. Soil reaction was determined to be 2.8. The tractive efficiency was 4.797 and engine torque 80.0NM. The length of the drawbar was able to allow the tractor to make a sharp turn without the rear tyres fouling the trailer. The trailer was suitable for use to transport photovoltaic power source and postharvest equipment such as threshers, graters, millers, etc. to point of usage in remote rural locations where there is lack of grid electricity.

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