Research Paper

DESIGN AND FABRICATION OF AN OPTIMIZED LOW COST CARGO-BEARING TRICYCLE

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ABSTRACT

The aim of the work was to design and fabricate an optimized low cost cargo-bearing tricycle which will fulfill the market demand in terms of cost and functionality, and also suitable for Nigerian roads. The integral construction produced a stronger and lighter vehicle which is very cheap when compared to the existing models in the market. The structure can withstand various static dynamic loads, which implied that the body shell is capable of bearing the various frame stresses. The arrangement of the various body panels to form a unitary structure of sufficient strength helped to resist the forces that act in the vehicle body. The floor and roof panels resist the sagging effect caused by the weight of the occupants and cargo. The stresses range from 3.2 MPa to 37.8MPa. The torque of 1372.71N was required to accelerate the tricycle and was derived from multiplying the tractive effort by the radius of the tire used. The material used for the chassis frame (cold rolled steel) has yield strength of 220.6 MPa, while point of maximum stress is 37.8 MPa giving a factor of safety of about 5.0 which is within a safe range. The objective of the research was fully met as the optimization of the existing tricycles was achieved in terms of ergonomics and strength, as well as in the cost effectiveness of the product.

KEYWORDS: analysis, cargo, design, fabricate, force, frame, load bearing, vehicle, transportation.

1. INTRODUCTION

Tricycles are three wheeled vehicles which is either human powered or motorized. Human powered tricycles are three-wheeled vehicles which rely on pedal power to move between destinations whereas Motorized tricycles are three-wheeled vehicles based on the same technology as motorcycles, and powered by electric motors, motorcycle, scooter or car engines.

According to Dike (2012), transportation is the pivot of the socio-economic development of nations. Essential in towns and cities is cargo transportation which caters for the movement of loads for the different purposes and human activities. Since the introduction of motorized tri-cycles (auto rickshaw) in Nigeria to bridge the gap on the ban of motorcycles in some cities, and solve the difficulties in transportation experienced by individuals who cannot afford private cars, the demand for tri-cycles in the nation has increased.

Akaigwe (2010) stated that the development and production of automobiles in Nigeria are currently much relying on foreign technology and sometimes do not fulfill the market demand in terms of costs, technological advancement and transportation efficiency. This research was proposed sequel to the need to device a means of manufacturing standardized load-bearing tricycles locally with cost effective local content that will meet the demand of Nigerian farmers. Secondly, the conventional motorized cargo tri-cycles have the load carrying capacity of 320kg, which has limited the use of tricycles for cargo purposes. This work intends to optimize the load carrying capacity to 600kg.

These could be achieved through the following objectives: the meticulous selection and use of cheap locally sourced materials in the production of the tricycle, the optimization of the ground clearance of the tricycle, the modification of the tricycle's cargo box, the optimization of the ergonomic suitability of the driver's seat, the application of good aesthetic quality and good body finishing to the tricycle.

A thorough and wholistic research was made on the entire make up, specifications and dimensions of the existing different models of Tricycle. After which modifications were made at the design stage to enhance the efficiency and optimize the performance of the prototype. The modifications included optimized load carrying capacity, durability, fuel efficiency, and low cost. Ergonomics also played a vital role in the research as it was employed in establishing several dimensions for driver and passenger comfort.

The economic importance of the work include effective utilization of cheap materials and resources, conservation of foreign exchange reserves, generation of employment leading to an increase in national income and acquisition of technological know-how. The design will be based on enhanced load carrying capacity, improved ride comfort in the form of ergonomically enhanced seating, and meticulous material selection to enhance cost reduction.

2. MATERIALS AND METHODS

2.1 Chassis Frame

The chassis of a frame serves two purposes: to support various components like Engine, Suspension system, Transmission system, Steering column, Brakes etc. and to withstand static and dynamic loads without undue deflection or twisting.

The following loads act on an automobile chassis, weight of the vehicle and the passengers causing vertical bending of the side members, vertical loads when the vehicle passes over a bump or a ditch, resulting in longitudinal torsion due to the lifting or lowering of one wheel, while the other wheels are at the usual road level, loads due to road camber, side wind, cornering force while taking a turn, resulting in lateral bending of the side members, loads due to wheel impact with road obstacles (when a particular wheel remains obstructed while the other wheels tend to move forward, distorting the frame to a parallelogram shape), engine torque and braking torque tending to bend the side members in a vertical plane and sudden impact loads during a collision, which may result in a general collapse. (Shukla et al., 2001).

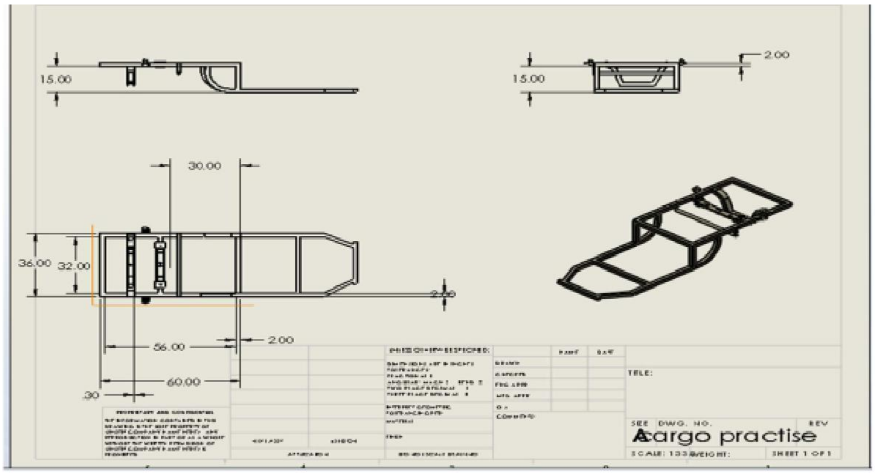

Fig. 1: Chassis frame (Top, side, back, and isometric) with Computer Aided Design (CAD)

The chassis construction adopted is the Frameless or unitary construction. According to Shukla et al., (2001), in frameless chassis construction, the heavy side members are eliminated, the floor is strengthened by cross-members and the body is welded together.

As depicted in figure 2, the chassis frame is primarily split into the following three divisions:

1. Steering column with front suspension
2. Entire frame from steering column to the rear suspension and
3. Rear suspension.

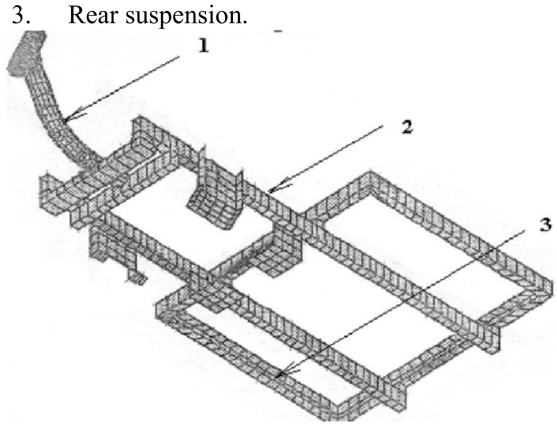

Fig. 2: Schematic diagram of a three wheel cargo Chassis Frame (Shukla et al., 2001)

Another factor that influenced the choice is the availability of both material and technology to work on these materials in the institution. In the chassis frame design, the aerodynamics stability was also considered, and was resolved with the application of Computer Aided Design (CAD) software - Solidworks. The software aided with the stress analysis tests, the force analysis tests, and the deformation analysis which were done using the Finite Element Analysis software, solidworks simulation software. Solidworks offered a better alternative to the manual method of calculating for the force acting on frame, as well as the calculation of the stresses acting on the different members of the body. Finite Element Software (FES) analysis software divided the whole element into smaller parts called elements and analyses each of the elements individually for whatever intent. The boundary conditions are limitations/ranges to which the problem has been set.

The need for a reasonably high value of the Factor of Safety (FOS) is justified by the fact that the work deals with human (driver) and his goods, as life and goods need to be secured. This explained the adoption of a minimum FOS value of about 5, which is justified by the project.

2.2 Chassis Frame Design and Analysis

According to Giri (2013), the various loads acting on a vehicle's frame can be classified as short duration load, momentary duration load, impact loads, inertia load, static loads, and over loads. Figure 3 depicts the loads distributed along the beams of the chassis frame. Major loads considered include: chassis frame mass 61 kg, engine mass 31.5 kg, cargo box mass 30.1 kg, load in cargo box 600 kg, average of 75kg per person for the driver/passenger masses and the skeleton mass of 49 kg.

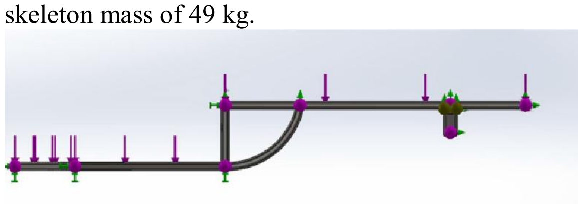

Fig. 3: Major loads acting on the chassis frame

2.3 The Control Systems

The control system comprises of the steering system and braking system.

2.3.1 Steering System Design

According to Heisler (2002), "the steering gear box offers two main functions; gear reduction between the input steering handle and the output drop arm (Pitman arm), and redirection of the input to output axis of rotation through a right angle." A steering system must offer sufficient precision for the driver to actually sense what is happening at the front tires contact patch as well as enough "feel" to sense the approach to cornering limit of the front tires. It must be structurally stiff to avoid components deflections. The steering must be fast enough for the vehicle's response to steering and steering correction to happen almost instantaneous and it must also have some self-returning action. Riley (2008) pointed out that the bounce and steering movements of the wheels provide for a variety of simultaneous needs; they provide steering input for directional control, compensate for (or utilize) body roll to improve cornering ability, and also move vertically in response to roadway irregularities in order to smooth out the ride and maintain adhesion.

Heisler (2002), observed that the feel, feedback and self-returning actions are function of the kingpin inclination, scrub radius, castor angle and self-aligning torque characteristics of the front tire. To maintain a particular direction of a vehicle, the steering handle must be constantly manipulated. To achieve this, the driver will have to monitor some important factors which are beyond visual perception (visible deviation and desired direction). These factors would include for example, the roll inclination of the body, the feeling of being held steady in seat (transverse acceleration) and the self-centering torque the driver will feel through the steering wheel.

Steer Angle (δ)

This is defined as the angle between the front of the vehicle and the steered wheel direction. The steer angle required to make a turn with no consideration for tire slip can be calculated from the equation 3.

$$\delta = a\tan\frac{L}{R} \qquad (3)$$

Where a = wheel track = 120 mm, L = wheel base = 2000 mm, R = wheel radius

Total height of each tire,

$$H_T = \left(203.2 + (101.6 \times 2)\right) = 406.4\ \text{mm}$$

Radius of each tire is 406.4/2 = R = 203.2 mm

$$\delta = 120 \times \tan\frac{2016}{203.2} \quad \delta = 21^0$$

Steering Radius

This is an important aspect when it comes to low speed performance, especially when turning around the vehicle or during parking. The radius is determined by the wheelbase and the wheels turning angle. Shorter wheel base together with high steering angle gives a sharper turn and longer wheelbase together with low steering angle equals the opposite. For the tricycle, the wheelbase is the distance between the front wheel and the centre of the rear wheels.

The steering radius can be derived by drawing a perpendicular line from the rear wheels and the front wheel. Where the lines meet, is the middle point of the turning circle i.e. the distance will be the steering radius.

Mathematically, it can be calculated with the equation below

$$r = \frac{w}{\delta\cos(\emptyset)} \qquad (4)$$

Where r = approximate radius, w = wheelbase, δ = steer angle, $\emptyset$ = caster angle of the steering axis

2.3.2 The Braking System

The brake adopted for the rear of the tricycle is the drum brake, which is a brake in which the friction is caused by a set of shoes or pads that press against the inner surface of a rotating drum. The drum is connected to a rotating wheel. This is employed to stop or slow down the speed of the vehicle. However, the disk brakes which are generally more efficient are applied for the front. According to BrakeWorks (2017), "the front brakes play a greater part in stopping the car than the rear ones, because braking throws the car weight forward on to the front wheels."

2.4 Wheel-track and Rollover

Duffy (2005), observed that the center of gravity is an important point to know while solving problems involving large objects, or unusually-shaped objects, as the weight can be considered to act at the center of gravity. In order to prevent a vehicle from rolling over, it is important to keep its center of gravity as close as possible to the ground. This is especially important for vehicles with a narrow wheel track. Figure 10 shows the rear of a narrow vehicle with the forces acting upon it during a steady state turn to the right. Assuming that the tyres will not slide, the maximum lateral acceleration application before roll over can be calculated when the vehicle is on the limit of rollover, when Fzr = Fyr = 0.

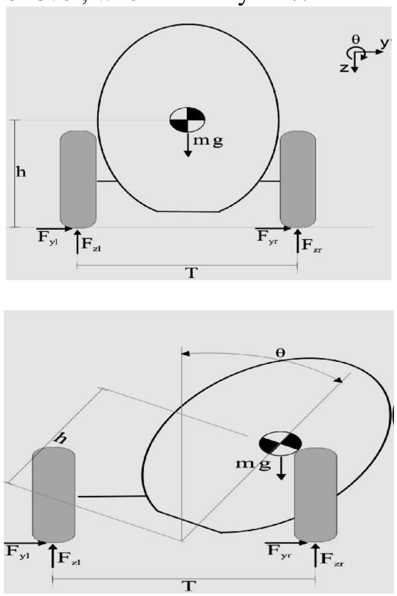

Fig. 4 (a) and (b): Forces acting on a narrow vehicle

Taking moments around the centre of gravity:

$$\sum M_{cg} = \frac{F_{zl}T}{2} - F_{yl}h = 0 \qquad (13)$$

In this limiting condition, the weight of the vehicle is supported completely by the left hand tyres:

$$F_{zl} = mg \qquad (14)$$

and the cornering force on the left hand tyres is equal to the force due to the lateral acceleration:

$$F_{yl} = mw^2R = \frac{mV^2}{R} ma_y \qquad (15)$$

Combining equations 13, 14 and 15, the maximum lateral acceleration, $a_{y,max}$ is governed by equation 16.

$$a_{y,max} = \frac{gT}{2h} \qquad (16)$$

This shows that for a four-wheeled vehicle with equal front and rear track, the maximum achievable lateral acceleration is determined by the ratio of half the wheel track and the height of the centre of mass. A modern tyre has an adhesion limit that will generate maximum forces equating to a lateral acceleration of approximately 10 m/s^2 and any vehicle should therefore be designed to have a rollover limit higher than this. For a narrow vehicle like the tricycle, with a wheel track of 0.8m, this would equate to having a centre of gravity height of 0.4m. To achieve this it would be necessary to position all the vehicle components and the driver very low to the ground. This would have a detrimental effect on accessibility, ground clearance and leave the driver feeling very vulnerable towards other vehicles.

By tilting the centre of mass towards the centre of the curve, the vehicle's tendency to overturn is reduced. Taking moments about the CoG again:

$$\sum M_{cg} = F_{zl}\left(h\sin\theta + \frac{T}{2}\right) - F_{yl}h\cos\theta = 0 \qquad (17)$$

This results in the expression describing the maximum lateral acceleration:

$$a_{y,max} = \frac{g\left(h\sin\theta + \frac{T}{2}\right)}{h\cos\theta} \quad (18)$$

It should be noted that with three-wheeled vehicles, the axis about which the vehicle will roll is not in the centre of the vehicle, but about the line joining the front wheel to the rear tyre which is on the outside of the curve. As the centre of mass will be located somewhere between the front and the rear wheels, the track of the rear wheels must be multiplied by the ratio of the longitudinal position of the centre of mass a and the wheelbase of the vehicle L to obtain its distance from the roll axis of the vehicle. It is assumed that that the vehicle is symmetrical. Including this term, equation 18 becomes:

$$a_{y,max} = \frac{g\left(h\sin\theta + \frac{Ta}{2L}\right)}{h\cos\theta} \quad (19)$$

As $\frac{a}{L} < 1$ the resistance to roll-over of a three-wheeled vehicle is less than that of four-wheeled vehicle. Shifting the centre of mass is therefore a necessity to ensure the stability of a narrow track three-wheeled vehicle.

2.5 The Gear System

The gear system adopted for the tricycle is a system of five sliding gears (four forward and one reverse gear, manual transmission). The gearbox sitting is between the crankshaft and the driveshaft. The tricycle requires a huge amount of force and very little speed to get it moving, so the driver uses a low gear when initiating movement from a point of rest. In effect, the gearbox is reducing the speed of the engine greatly but increasing its force in the same proportion to get the tricycle moving. Once the tricycle is in motion, the driver switches to a higher gear. Changing gears entail using the engine's power in different ways to match changing driving conditions. The rider uses the gearshift to make the engine generate more force or more speed depending on whether hill-climbing power, acceleration from a standstill, or pure speed is needed.

2.6 The Clutch

The clutch used is a wet multi disc type where it is used to connect the engine and the gear box. Here the clutch enables to crank and start the engine, disengage the transmission and change the gear to alter the torque on the wheels. The mechanism linkages are connected in such a way that the force to operate the clutch gets increased. According to Nice and Bryant (2017), “the amount of force the clutch can hold depends on the friction between the clutch plate and the flywheel, and how much force the spring puts on the pressure plate.” They concluded that when the clutch handle is pressed, a cable pushes on the release fork, which presses the throw-out bearing against the middle of the diaphragm spring. As the middle of the diaphragm spring is pushed in, a series of pins near the outside of the spring causes the spring to pull the pressure plate away from the clutch disc. This releases the clutch from the spinning engine.

2.7 Body Design

This section buttresses the adopted design and material selection for the body frame, body exterior and body interior. The design process involves, concept development, body and cargo design or paper work, research and market survey, material selection and procurement, construction of body and cargo frame, measuring and cutting out of metal sheet and leather for covering frame, riveting and welding of sheet into frame, panel beating and body filling, surfacing and washing of body, finishing and painting

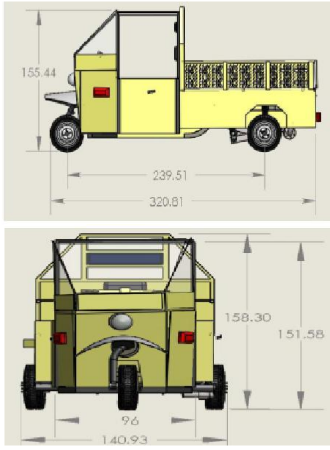

Fig. 5 (a) and (b): Side and Front views of tricycle with dimensions in cm (CAD)

2.7.1 Body Frame

There are two body construction types available: the integrated and the body and chassis construction. The latter was adopted for the design, as it suits the design intent and also makes it easier to work independently on the chassis and body frames, this makes it easy for repair purposes and enhanced strength for the whole assembly.

Frame material has been selected based on strength, availability and cost. The frame material adopted was 45mm and 25mm mild steel squared hollow pipe (1mm thickness), 1mm flat bar and 50 mm circular hollow pipe. These materials were selected because they have low stress at the same magnitude of force applied compared to some other available materials.

2.7.2 Body Exterior

The design intent is to build a body that not only looks appealing but also has better interactions with air flow, and reasonably strong and rigid. In the material selection, it was settled for 1.2mm sheet metal. Sheet metals are streamlined and this reduces aerodynamic drag. Rivets were applied to primarily hold the sheets in place, and subsequently welded permanently. Steel has a specific gravity of 7.8 and a Young’s modulus of 206.84GPa and is prone to corrosion; this was however minimized by treating the body with anti-corrosion before painting. Two dwarf doors were fabricated by the two sides of the front part of the body to ensure driver and passenger safety.

2.7.3 Cargo Box

The cargo box body was formed with 18 gauge sheet metal which has thickness of 1.2mm. The frame of the cargo box was produced using 25mm square hollow pipes, 40mm hollow circular pipes with thickness of 1.5mm and rectangular pipes. The cargo box is fitted with a door by the right and another by the left to enable easy loading and unloading of items. The floor of the cargo box was also made of 1.2mm sheet metal (rough surface type) and contains the bonnet cover to enable service and maintenance of engine and other components.

2.7.4 Important Considerations in the Body Design

Air resistance $R_a = \frac{1}{2} C_d \rho A V^2 = 0.2082 \text{kg/s}$ (20)

Where; C_d = aerodynamic drag coefficient (0.44-0.5) for three wheelers, ρ = density of air = 1.2250kg/m^3, A= projected area of the vehicle = 30.23m^2, V = velocity of the vehicle = 40mph.

- **a. Cab:** the driver's cabin is an open region by a part of the body.
- **b. Fascia:** this is the frontage of the vehicle visible to the driver. It includes the dashboard.
- **c.** Dashboard houses the controls and indicators.
- **d. Legroom:** this is the space provided for the most of legs of the driver and passengers. Sufficient legroom is essential for comfortable driving and travelling.
- **e. Headroom:** is the vertical distance inside the body between the floors to the ceiling. This dimension is based on the stability consideration of the vehicle and position of centre of gravity from the ground level depends on this height.
- **f. Shoulder room:** is a clear horizontal distance available inside the body.

2.8 Seat Design

In the course of design and construction of the seats, some considerations were made based on ergonomics, strength, and weight of the seat and availability of materials. This had a lot of influence on the material selection. The seat was designed to accommodate a driver and a passenger.

In the seat frame construction, 50mm circular hollow pipe and 45mm square hollow pipes were employed. Both pipes have a thickness of 1mm. These pipes offer light weight which enhanced less aerodynamic drag and fuel efficiency. The frame of the seat was fabricated with electric arc welding. Some of the joints are lap joints, butt joints and corner joints. Six inches high resilient foam was used on the seat base and while 3 inches off-cut back foam was used on the back rest. The entire upholstery was fastened to the seat frame using bolts and nuts. Leather material was used to upholster the seats. This was done mainly by cutting, tying and sewing the leather material to fit the seats.

2.9 The Engine

In the design of the tricycle, a single cylinder two stroke forced air cooled engine was used. A two stroke engine is an internal combustion engine which completes the power cycle in two strokes (upward and downward movement of the piston). The two stroke engine was selected for the following reasons:

Light Weight: The two stroke engine has less number of moving parts than the other more complex engines (four stroke engines). It also has a simple layout. This leads to the light weight.

- i. **Low Cost:** The two stroke engine is relatively cheap compared to the four stroke engine. This enhances the aim of the project which is achieving optimum load carrying capacity at low cost.
- ii. **High Power to Weight Ratio:** The two stroke engine has high power to weight ratio when compared to the four stroke engine. It requires just one crankshaft revolution to complete the power cycle, this is achieved by carrying out the intake and exhaust stroke as well as the compression and power stroke simultaneously. The implication of this is that a two stroke engine of a particular size has the potential to produce more power than a four stroke engine of the same size.

Although the mass of the tricycle is 755 kg, its frontal area is 2.07m^2.

2.9.1 Engine Design

Engine Displacement: This is the swept volume of all the pistons inside the cylinders of a reciprocating engine in a single movement from top dead centre to bottom dead centre. It does not include the total volume of the combustion chamber.

Engine displacement can be calculated with equation 21;

$$V_{sv} = n\frac{\pi}{4}{d_{bo}}^2 L_{st}\ (\text{cc or cm}^3) \qquad (21)$$

where;

V_{sv} = engine displacement or swept volume, d_{bo} = engine bore = 4.5 cm, L_{st} = engine stroke = 9.145 cm, and n = number of cylinders = 1

$$V_{sv} = \frac{\pi}{4} \times 4.5^2 \times 9.145 = 145.45\ \text{cc}$$

If the exhaust port closes some distance called the trapped stroke, before the top dead centre, the trapped swept volume of any cylinder is given by

$$V_{ts} = n\frac{\pi}{4}{d_{bo}}^2 L_{ts}\ (\text{cc or cm}^3) \qquad (22)$$

where V_{ts} = trapped swept volume of any cylinder, and L_{ts} = trapped stroke before top dead center.

2.9.2 Required Acceleration of the Tricycle

To obtain the acceleration of the tricycle, consideration is taken from a condition of rest (0 km/h), to the time (say 10 seconds) when the vehicle attains a velocity of 30km/h (for most tricycles).

Acceleration, a_m $a_m = \frac{v_2 - v_1}{t}$ (23)

$$a_m = \frac{30-0}{10} \times \frac{1000}{3600} = 0.83\ \text{m/s}^2$$

2.9.3 Thrust Force (Tractive Effort) Required for Motion, F_T

The thrust force represents the force needed for the tricycle to be in motion. It is the sum of the force due to acceleration and the force due to road resistance. The road resistance to vehicle movement is given in tractive resistance (KN). The tractive effort (KN) provides the propelling thrust at the tire to road boundary needed to overcome the tractive resistance. Thrust force, F_T, is given by the relation:

$$F_T = f_{aero} + f_{roll} + f_{grad} + f_{acc} \qquad (24)$$

$$F_T = C_d A V^2 + C_{rr} mg + \%\text{slope}.\, mg + ma \qquad (25)$$

$$F_T = \frac{\rho}{2} C_d A V^2 + mg\left(C_{rr} + \%\text{slope} + \frac{a}{g}\right) \qquad (26)$$

Where ρ = air density = 1.2kg/m^3, A = frontal area, m^2= 2.07 m^2, C_d = aerodynamic drag coefficient (0.44), V = air velocity, m/s = 6.5 m/s, C_{rr} = rolling resistance co-efficient (approximately 0.015), % slope is rise/run (= tan θ, $\theta = 15^0$)

$$F_T = \left(\frac{1.2}{2} \times 0.44 \times 2.07 \times 6.5^2\right) + 755 \times 9.81\left(0.015 + \tan 15 + \frac{0.83}{9.81}\right) = 2745.42\text{N}$$

2.9.4 Torque required to accelerate the Tricycle, T

The torque required to accelerate the tricycle was derived from multiplying the tractive effort by the radius of the tire used.

$$T = F \times R_{tyre} \quad (27)$$

Force required at the two back tires to move the car is $F = 2745.42N$

Force required at each tire is

$$\frac{F}{2} = \frac{27\ 4542}{2} = 1372.71N$$

The tire is a radial one with size chosen as 4.00 - 8. This is interpreted as: Width – 4 inches (101.6 mm), Side wall Height – 4 inches (101.6 mm), Rim Diameter – 8 inches (203.2 mm), and Wheel Base – 2000 mm. The choice for the tire selection size was due to market availability and width consideration to give the tricycle an enhanced dynamic balance.

Total height of each tire,

$$H_T = \big(203.2 + (101.6 \times 2)\big) = 406.4 \text{ mm}$$

Radius of each tire is 406.4/2 = R = 203.2 mm = 0.2032m

Torque required at each wheel,

$$T = \frac{F}{2} \times R = 1372.71 \times 0.2032 = 278.93Nm$$

Torque required at both back wheels,

$$T_b = 2T = 2 \times 278.93 = 557.86Nm$$

For the project, it has been determined that the combined torque available at the rear wheels is 557.86Nm (as calculated in equation 27). This implies that any engine that must be selected for the tricycle must possess a maximum torque of more than 557.86Nm.

The brake torque, T_b (this is the torque at the tires due to the transmission system). This is given by the relation in equation 28:

$$T_b = T_c \times D_G \times D_C \times D_D \quad (28)$$

Where, T_T = torque from the engine available to the tires, T_C = torque on the crank shaft, D_G = primary drive ratio of the gearbox, D_S = drive ratio of the shaft, D_D = drive ratio of differential.

The Engine Specification is given as follows: Model: Bajaj RE, Type: Single cylinder, 2-stroke forced air cooler, Weight: 31.5 kg, Displacement: 145.45 cc, Max. power: 7.00 HP, 5.15 KW at 5000 rpm, Transmission: 4 forward and 1 reverse, Cooling Medium: Air, Fuel: Gasoline, Fuel consumption:18 to 20 km/liter.

'cc' is cubic centimeters which is a measure of volume. It is a parameter for describing the total volume of the engines' cylinders which is filled with a mixture of air and fuel. It is often referred to as the displacement volume that suggests the power produced by an engine.

To determine if the above engine is suitable forther design, equation 29 is employed thus:

T_b = 557.86Nm, T_C = ?, D_G = 4.5, D_S = 3.75, D_D = 5

$$T_C = \frac{T_b}{D_G \times D_{S\times} \times D_D} \quad (29)$$

$$T_C = \frac{557.86}{4.5 \times 3.75 \times 5} = 6.6 \text{ N m}$$

The value calculated above justifies the choice of the engine as it's rated maximum torque of 12.1Nm is greater than the calculated value of 6.6Nm above.

2.10 Cost of Materials

The total cost of materials purchased after the design and material selection is five hundred and two dollars, thereby meeting up with the research's objective of cost effectiveness.

Fig. 6: Side view of the completed load-bearing tricycle.

3. ANALYSIS OF THE TRICYCLE'S PERFORMANCE

The entire body consists of the driver/passenger section and the cargo section. The vehicle floor (driver/passenger and cargo section) was formed with 18 gauge 1.2mm sheet metals (mild steel) reinforced with 1mm square pipes beneath but in the case of the cargo box floor, the rough surface type of sheet metal was specifically used. This helped to achieve a firm rigid floor capable of withstanding all forms of loading conditions it will be subjected to.

The body of the driver/passenger section was also formed with the 18 gauge 1.2mm sheet metal (mild steel). This was used because it offers excellent body finishing advantages and also, the sheet metals are streamlined leading to lower aerodynamic drag. In addition to that, the ductility of the metal helped to form exact shapes in accordance with our intended design. The body shell was fabricated by building a skeleton or space frame which provided a high structural strength. The steel, roof and other parts were attached to the frame. The roof was formed with leather to enhance low cost, light weight and heat absorption by conduction. Two dwarf doors were also attached to both sides of the front to ensure optimum safety for the driver and passenger.

The body shape depends on a number of factors; these include appealing shape, comfort, and good performance during its movement through the air. A vehicle body with the aerodynamic shape as such passes with least resistance through the air thereby improving the fuel economy.

The starter is installed in a horizontal position next to the engine crank case so that the drive pinion is in a position to mesh with the flywheel or drive plate ring gear. The starter is a manual hand starter which when pulled up by the driver starts the engine.

4. CONCLUSION

The aim of designing and fabricating a robust load-bearing tricycle with sixty five percent local content was successfully achieved as all the set out objectives were met. The front and rear of the rigid body were fixed with sub-frames which were designed to withstand impacts, while the crumple zones of the body will absorb the shock of a collision to reduce the rate of deceleration experienced by the occupants. The meticulous selection of the materials used to produce the chassis yielded optimum performance at low cost, as it was produced with mild steel hollow square pipe of 2.5 mm thickness. The use of the material with high yield strength provided the tricycle the support it needed to carry the stipulated load of 755 kg. The driver/passenger seat frame is bolted to the floor pan and part of it is welded to the body skeleton. Tests show that the seating accommodation is comfortable, sufficient leg-room for driver/passengers are available and the driver can position himself suitably to control the accelerator and clutch, and also provide effective leverage to the brake pedal for emergency. The seats were positioned to support the lower part of the body and back against any lateral forces if experienced; for good visibility towards the front and sides and for the driver's natural aim movement to steer and change gear with the minimum effort.

Whatwhen (2017), noted that during acceleration, the torque of the rear wheel pushes the forward part of the driving tyres downward, as the front of the driving axle housing is lifted producing rear-ward weight transfer, which tends to lift the tyres from the ground reducing tyre-to-road friction, thereby reducing steering control.

The aerodynamic feature of the vehicle was enhanced by the streamlined body structure hence higher operational speed and fuel economy. The ergonomic suitability of the driver/passenger seats was greatly enhanced due to the research carried out and also the adoption of SAE standard for seat design. The ground clearance of the tricycle was optimized to 200mm which is better than the ground clearance of the conventional tricycles. Also, the cargo box was efficiently modified to accommodate more loads. Hence, the overall objectives of the research have been successfully achieved.

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