Numerical investigation of frame for human powered flywheel equipped cycle rickshaw

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Abstract. Recent awareness in fossil fuel depletion due to large consumption with regard of population number growth from time to time, and environment degradation due to fossil fuel combustion emission has generated. This research focuses on the design of human powered flywheel equipped cycle rickshaw. The operating mechanism of this vehicle is same as the upright bicycle. The study conducted by reviewing different related previous works. The main objective of this work is designing flywheel equipped cycle rickshaw, to harvest kinetic energy lost during braking or slow down for later use. This done by using a mechanism incorporated with flywheel and clutch system. The study is carried out for design of the frame. The frame of this work cycle rickshaw designed by using both upright bicycle fit data and anthropometrics data in order to develop ergonomic and rigid frame. After the needed component geometry and dimension analyzed the model of cycle rickshaw components developed by using CATIA software. The design considers both static and dynamic condition. For FE analysis ANSYS 15 is used to find out total deformation, equivalent (von mises) stress, maximum shear stress and factor of safety.

Keywords: cycle rickshaw, Human powered, flywheel, Anthropometrics, pollution free, cycle rickshaw performance.

1. Introduction
The First Cycle rickshaw improvement project was launched in the early 1970’s. In 1973 Stuart Wilson, an engineering lecturer at Oxford University, designed a differential for use in Indian rickshaws. The aim was to overcome the problem that only one of the rear wheels was driven. The following year a “Mark-2” version was produced which was completely re-designed rickshaw. This was named ‘Oxtrike’. The main features of the Oxtrike were a 3-speed Sturmey-Archer gear (which allowed three gearings smaller, stronger wheels; chassis made of box section steel sheet; powerful foot brake and the differential) [1]. The plan was to dispatch the vehicle in kit form for local assembly. Then as the Oxtrike became more widely used, kits would be limited to complex components which couldn’t be locally made (e.g. 3-speed free wheel, etc.). Oxtrike was such a radically different design.
Many of its components were unable in third world countries. Local rickshaw makers would have had to learn a completely new design [2] [3]. Since people come in a variety of sizes, and their bodies are not built in the same proportion, “design for an average” (50th percentile) will not work. The goal of product design is to accommodate as many users as possible. A number of countries in the world have sampled sufficient numbers of their respective population to have developed a national anthropometric profile [4]. The bicycle and the human powered vehicle industry, which are currently generates no pollution. Human powered vehicles or non-motorized transport, such as bicycle, tricycle or cycles rickshaws are some of the purest forms of transportation. [5]. Transport tricycles, also known as cycle rickshaws, is a three wheeled tricycle design, pedaled by a human driver in the front, and with a back seat in the rear for passengers or for conveying goods.[6]

It is related with economy that is utilized for movement of people and goods from one place to another. Various means of transportation can be self-propelled or manually driven. Every normal human being is using either one or the other form of transportation facilities available. Among transportation means petroleum fuel powered road transport is the nearest and flexible to people which allows even to operate from door-to-door over short distance at the most competitive prices. However, most road transportation that internal combustion engine based propulsion it uses petroleum fuel and it causes environmental impacts. Moreover, in this time transportation of both goods and humans increased rapidly with regard of population and economic growth. Also transportation is the backbone for development of civilization [7] [8].

This study helps to reduce environment degradation, noise and air pollution. Because unlike internal combustion engine propelled vehicle, flywheel equipped cycle rickshaw driven by human muscle power which is eco-friend, quiet and pollution free. The other aspect is that with growing population, there is still growing need for local transportation. If this need is entirely met through internal combustion engine propelled vehicles, there will be additional import requirement of petroleum products. Also, flywheel equipped cycle rickshaw, used as a mode of localized transport, can contribute to income generation and employment for uneducated unemployed youths, wellbeing of their families and to the country’s economic development itself. This project is a way to design efficient human powered vehicle that potentially will serve as a partial solution to these problems. This work goal was to design human powered flywheel equipped cycle rickshaw are commuter vehicle. Design lay out of cycle rickshaw is a delta-style with rear-wheels drive for a single rider and three passengers. One of the most important requirements is that the vehicle must have an optimum strength, weight and low price. In order to achieve this goal, it is necessary to use the optimal material and suitable frame to ensure the required quality with the lowest cost and simple construction. Finally, to represent 3D model of new cycle rickshaw and it’s component CATIA V5 R20 software are used and ANSYS 15.07 used as well for FEM analysis. The main objective of this work to frame for human powered flywheel equipped cycle rickshaw for integrated ergonomically and possible light weight frame.

2. Materials and methods

The overall dimension of the frame has been determined from the anthropometric data of the 95% population, bicycle frame size that from upright bicycle manufacturing manual data and standard machine elements. After all, needed dimension obtained 3D CAD modeling of the frame and components of cycle rickshaw generated in CATIA V5R20 and saved in CATIA format or IGIS format. That saved model imported to ANSYS 15 to preform finite element analysis. In addition, that ANSYS space claim used for cleaning and repairing the model created in CATIA software in order to increase mesh refinement and result accuracy.

2.1. Design specifications

- Weight of vehicle below 70 kg
- Maximum load: 240 kg (rider plus two passengers each 80kg).
- Wheelbase: up to 1.95 m.
The new cycle rickshaw operating mechanism must be like bicycle except KERS.
The frame of the new cycle rickshaw must be able to accommodate varying size of 95% population.
The maximum speed of the vehicle not exceeding 30 km/hr.
The cycle rickshaw will be steered through the bicycle’s handle bars at 1:1 steering ratio will be maintained.
610 mm (24 inches) both rear and front wheels.
This new cycle rickshaw compatible with existing parts.

2.2. Frame design
A cycle rickshaw frame is the main supporting structure to which all other components are attached. The main functions of a frame in cycle rickshaw are to support load of passengers, rider, and mechanical components of cycle rickshaw and to deal with static and dynamic loads, without undue deflection. The various loads dealt with frame includes Weight of the other mechanical component, rider, passengers loads causing vertical bending of the member transmitted by going over uneven surfaces for Sudden impacts from collisions in order to support these all, loads the frame should be strong enough to withstand the rigorous force that will act on it but at the same time it should be as light in weight as possible to increase efficiency [8].

2.3. Frame section
Generally, frame of a vehicle made from the following section such as channel, box and tubular section shown in figure.1

![Figure 1. Frame Sections type](image)

Channel section used in long member of the frame since it has good resistance to bending. Box section used in short members of the frame and it has good resistance to bending and torsion. While tubular section is used in the frame which subjected to torsion. Therefore, box and tubular section is selected for this work base on load carrying character criteria.

2.4. Frame geometry analysis
Cycle rickshaw frame composed of upright bicycle frame and rear lower passenger carriage frame. In order to determine overall length and width of cycle rickshaw frame eleven dimension of the human body are enough. See figures 2. Bicycle frame geometry needed during cycle rickshaw design. For this work upright bicycle frame has been selected based on 50% of the adult population size from road bikes on sale in the UK.
The height and inseam of the rider is 1719 mm and 816 mm respectively then select the correct size of bike frame from table that is 54 cm.

2.5. Dimension for passenger carriage frame
Rear total track width = number of passenger * hip breath of passenger + space for side support. From anthropometric 95th % data been used for design. The cycle rickshaw passenger compartment carrying capacity is two passengers.
Rear total track width = (2×420 mm) + 60 mm = 900 mm
Length of passenger compartment = Buttock-knee length + assume little free space of passage foot rest and rear support.
Length of passenger compartment = 660 mm + 100 mm = 760 mm ≈ 800 mm

2.6. CAD Modeling of the frame
The four CAD model concepts of the frame was developed based on above frame size analysis data. That data obtained from anthropometrics and selected bicycle frame size. These CAD models concepts was developed on CATIA V5.
Two section type (i.e. box and tabular) has been used to develop CAD models and with standard section size of 35mm diameter and 2.5 mm thick head tube, 30mm diameter tube with 1.5mm thickness, for box section 1.5 mm thick and (30x30) mm, and (35 x 30) mm was used.
Figure 3. Flywheel equipped cycle rickshaw frame model concepts
From four developed frame model concept model (d) concept has been selected based on its simple to construction, less welded parts, compatible free space at the center of passenger carriage frame for purpose of mounting kinetic energy recovery system and less mass when it compared with other three model concept. The mass of each model concept is, for fig 3 (a) 22.7kg, fig 3 (b) 19.3kg, fig 3 (c) 15.4kg and fig 3 (d) 11.7kg, this obtained from CATIA after select frame that is steel. The CATIA software automatically calculate mass frame using material density and frame volume.

2.7. Frame model
CAD model of fly wheel equipped cycle rickshaw frame has been prepared in CATIA V5 as shown below in figure 4. The dimensions were obtained from anthropometrics, bicycle frame size and other parts. The thickness size of each section of the frame is considered relative to steel bicycle and standard parts. The size of section used for modeling final frame is head tube (160mm length, 35mm diameter and 2.5mm thickness), for top, down, seat stay and cross tubes (square tube 30x30 (mm) and 1.5mm thickness), for chain stay and passenger carriage tubes (rectangular tube 30x35(mm) and 1.5mm thickness), seat tube (30mm diameter, 450mm length and 1mm thickness), BB shell (68mm width, 42mm outer diameter and 35 inner diameter), rear axle support plate (100x180 (mm) plate and 4 mm thickness), KERS support tube ( 20mm outer diameter and 1.5 mm thickness) for further and detail dimension see appendix D.

Figure 4. Fly wheel equipped cycle rickshaw frame

2.8. Frame Material
Material selection for human powered vehicle frame applications plays very important role in providing the desired strength, endurance, safety, efficient performance and reliability to the vehicle [32]. The selection of material for cycle rickshaw frame is done by detailed study of properties of material regarding strength, weight, manufacturability, cost and availability results found that steel alloy AISI 4340. But prefer to use AISI 4130 over the rest carbon steel because of its higher yield strength and
corrosion resistant. AISI 4130 high strength to weight ratio is essential property because cycle rickshaw human powered vehicle need less weight frame to improve its performance.[32]

2.9. Meshed frame model
Meshing for the new cycle rickshaw frame model was done using the automated ANSYS meshing refinement feature. That with fine relevance center, fine smoothing and with 4mm element size, these parameters controlled on ANSYS global mesh control features. Finally, the frame meshed to 430832 nodes and 217457 elements numbers. The meshed model is shown in figure 5.

![Meshed new cycle rickshaw frame model](image)

Figure 5. Meshed new cycle rickshaw frame model

2.10. Boundary condition or loading
The model fixed in all degrees of freedom near the supports; fixed support is applied at bottom side of head tube and rear wheel axle support plates. It shown in Figure 6. The loading conditions are static start up and steady state pedaling. For those scenarios analysis simulation had done in similar way except rider loading.

2.11. Static start up
A 70kg rider is applied maximum effort to bottom bracket to accelerate cycle rickshaw with 160kg passenger on seat mount, 8kg flywheel on mount and other mechanical components from stand position. For this scenario the rider is out of the saddle. The cycle rickshaw frame is in vertical equilibrium with head tube (at A) and rear drive axle assembling plate hole were fixed (at A but for multi face selection ANSYS work bench label only one point).

The following figure 7. shows that the loading and boundary condition on a cycle rickshaw frame, this load is applied according to the design of frame. Also the boundary condition is applied at fixed position of a model which is consider as a supports, the load is applied considering weight shift during operating condition of cycle rickshaw it taken twice of static load on each load application point.
2.12. Steady state pedaling
From total load of rider 60% load (824N) considered as applied on seat tube and 40% load (550N) applied on pedal or BB bearing. But other loads not changed it is the same as case one. Those all load applied to negative Z axis.

Figure 7 shows load and boundary application on frame for steady state pedaling condition.

3. Results and discussions
Finite element analysis is important to do a numerical simulation in order to find out how cycle rickshaw frame react when the rider, passengers and other mechanical system subject to weight load and dynamic load. In order to perform finite element analysis, FEA modeling process requires three types of input data such as geometry, material properties, and loading. After modeling the analysis of frame is done in ANSYS 15.07 workbench, for that purpose frame model preparing the in CATIA then it is imported to ANSYS workbench, the file is imported from CATIA by file>import>IGS. To carry out the analysis three scenarios are considering like start up, stand pedaling.

3.1. Result analysis for static start up condition
The following Figure 4.10 shows the result of figure 8 (a) total deflection, figure 8 (b) equivalent (von-mises) stress and figure 8 (c) factor of safety, for static start up condition in the frame when the load of 1374N (at B), 3434N (at C) and 157N (at D) is applied for material AISI 4130. The red color shows the maximum simulation value of those parameters and blue color shows minimum simulation value of those parameters generated. But for factor of safety blue color shows maximum value and red color shows minimum value.
Figure 8. a. Total deformation

Figure 8. b. Equivalent Stress

Figure 8. c. Factor of safety

3.2. Result analysis for load for steady pedaling condition
The following Figure shows the result of figure 9 (a) total deflection, figure 9 (b) equivalent (von-mises) stress and figure 9 (c) factor safety for steady state pedaling condition in the frame when the load of 824N, 550N, 3434N and 157N is applied for material AISI 4130. The red color shows the Maximum simulation value of those parameters and blue color shows minimum simulation value of those parameters generated. But for factor of safety blue color shows maximum value and red color shows minimum value.
3.3. Comparison of Frame static structural analysis result

In static structural analysis of the cycle rickshaw frame done on ANSYS workbench 15 for static start up and steady state pedaling condition. And the result of total deformation, equivalent (von-mises) stress and factor of safety obtained and tabulated below in Table .1.

| Table 1. Frame simulation result | Static start up | Steady state pedaling |
|----------------------------------|-----------------|-----------------------|
| Maximum                          | Minimum         | Maximum               | Minimum               |
| Total deformation (mm)           | 0.88            | 0.91                  | 0                     |
| Equivalent Stress (Von-Mises)    | 163.19          | 167.77                | 0.0027                | 0.00168                |
| Factor of safety                 | 15              | 15                    | 2.67                  | 2.60                   |
From analysis result the total deformation under applied load of rider, passenger, other mechanical system Weight and operational dynamic load the maximum total deformation obtained around front leg mount of passenger seat and magnitude of 0.88mm for static startup and 0.91mm for steady pedaling condition as figure 8 (a) red colored counter shows. For both condition maximum total deformation value is less 1mm this indicates cycle rickshaw frame stiffness is feasible under application of these loads.

The simulation results for both static startup and steady pedaling condition revealed that the maximum stress or equivalent (von-mises) stress generated on the frame is of the magnitude of 163.19MPa and 167.77Mpa reactively which is less frame material yield strength. these stress found on rear axle mount plate. Also, The Factor of safety of the frame for static startup and steady pedaling condition on analysis was found to be of 2.67 and 2.6 reactively which means it can be considered practically feasible.

4. Conclusions
The frame of cycle rickshaw were designed on the basis of anthropometrics, this makes vehicle comfortable for both passenger and rider. Also integrated frame design increases stiffness and reduces the weight of the frame which in turn increases the performance of the vehicle. The frame was made of 35mm circular head tube 30x30 square and 30x35 rectangular AISI4130 steel tube with steering link constructed from 25mm AISI4130 steel tubing that successfully underwent a series of ANSYS static structural tests, it was able to support a 6867N vertical load (both static and dynamic loads). The maximum flywheel equipped cycle rickshaw speed was 30km/h. though that would increase with the addition of a larger front chain ring. The frame of flywheel equipped cycle rickshaw can withstand both full static load and dynamic load up to 6867N without any failure. The analysis shows that the equivalent stress of designed parts of flywheel equipped cycle rickshaw is less than material stress which means the factor of safety is greater than one.

5. Reference
[1] B. J. M. Rahman (2010), "Non-motorised public transport," Australasian Transport Research Forum, Vol 29, pp. 1-14.
[2] Sreevalsan Menon (2012), “Design and analysis of kinetic Energy recovery system in Bicycles,” International Journal of Innovative Research in Science, Engineering and Technology, vol. 2 (8), pp. 42-45.
[3] M. Wegener (1997), “Sustainable transport,” Journal of Transport Geography, vol. 3(5), pp. 177-190.
[4] J.A. Black (2002), Sustainable Urban Transportation: Performance Indicators and Some Analytical Approaches, Journal of Urban Planning and Development, vol. 128 (4), pp. 83-107
[5] S.S. Wilson (1974), The Cycle Rickshaw in appropriate Technology, Oxford University, vol. 1(2), pp. 15-28.
[6] Javakumar, “Design and analysis of light weight motor vehicle flywheel,” International Journal of Computer, vol. 4(7), pp 2360-2365.
[7] Sushama G Bawane (2012), Analysis and optimization of flywheel,” International Journal of mechanical engineering and robotics, Vol. 1(2), pp272-276.
[8] Prakash Kumar Sen (2015), “Study on Differential for Optimum Utilization in Automobile,” International Journal for Research in Applied Science & Engineering, Vol.3(5),pp 353-357.