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Development of an electric drive train for cycles as a sustainable means of transportation for a green environment

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Abstract

A reliable and sustainable means of human transportation is vital for the world's increasing pollution emissions and congestions on the motorways. The research aimed at and focused on developing an affordable electric drive train for cycles using the principle of Continuously Variable Transmission (CVT) to provide an interminable number of speed ratios by varying the pulley diameters. The planetary gears designed and installed within the CVT chamber provided a locking mechanism for the ring gear to provide forward transmission to the rear wheel where motion was stepped up through an open differential gear to propel the cycle forward. For stability and ease of manufacture and assembly, a tricycle concept was chosen and developed as a sustainable and alternative means of transportation. The developed electric drive train provides a 'green' and affordable means of human transportation in a world geared towards the elimination of pollution.

Keywords: Electric drive train, manufacture, transmission, sustainability, transportation

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1. Introduction

In recent years, motor vehicles have become the most common means of transport throughout the world, which people use in their daily lives. However, the use of motor vehicles has its own advantages and limitations. One of the biggest challenges of using motorized vehicles that are fuel powered is the unfortunate production of greenhouse gases and carbon emissions which ultimately and negatively affect the environment in different ways [1]. Many countries around the world have actually introduced legislation for penalizing users of motorized vehicles that emit more than the permissible amount of pollution in order to protect the environment, reduce pollution and the continued effects of climate change due to such emissions [2]. The Environmental Management Agency (EMA) of Zimbabwe for instance, regulates, sets policy and controls environmental issues in Zimbabwe. According to their air pollution control regulation, SI 72 of 2009, manufacturing and processing companies are taxed on pollution levels they emit where the tax amount depends on the concentration of the emissions and mass flows in their bid to promote the "polluter pays principle" [3]. On the other hand, some countries have also introduced incentives to reward companies for emissions below the permissible amount [4, 5].

The International Air Transport Association (IATA) also recognizes the need to address global challenges of climate change by pledging to reduce the amount of carbon emissions through the use of efficient fuels, 50% reduction carbon dioxide emissions by 2050 and taxation on carbon footprint to mitigate and assist in the effects of climate change [6]. IATA's commitment also goes beyond these targets to suggest improved technologies, use of sustainable low carbon fuels, use of efficient aircraft, modernized air traffic management systems and a global market-based measure to eradicate emissions [6]. All these measures and interventions demonstrate the importance of reducing carbon emissions in order to protect the environment for a sustainable future. According to the International Civil Aviation Organisation (ICAO) Airport Air Quality Manual concerning aircraft engine and vehicle emission standards and regulations, there is need to reduce pollutants such as NO_x and CO common in aircraft support vehicles [18]. The introduction of an efficient and sustainable bicycle would reduce these greenhouse gases to a great extent. Additionally, the US Environmental Protection Agency (EPA) has produced a Clean Air Act (CAA) to develop regulations to minimize emissions from vehicles and power plants since it was observed that carbon pollution was skyrocketing [19]. However, these regulations can only be affected with a change in attitude and mindset on how people commute within the confines of their workplaces. The incentives by IATA and other organizations are some of the several ways in which carbon emissions can be managed to reduce the damaging effect on the environment. One way to reduce such emissions would be the use of non-motorized or fuel powered mode of transportation in the form of cycles. Although this may not be popular with many people because of the seeming inconvenience, it is actually one of the recommended and healthy ways of getting from one point to another.

Bicycles are a very important means of transport in the modern world as they can be a very reliable and efficient mode of transport. They have become very common in many parts of the world such as China, Europe and Australia [7]. They have become the principal means of transport in many regions of the world. Bicycles have been around for over two centuries and have been continuously and rapidly improved over the ages. Engineers have been coming up with great ideas to improve the bicycle and its machine elements such as steering mechanisms, gearing system, chain drives and many more. Without these ideas and improvements, the bicycle would not be what it is today. However, a lot can still be done to improve the current bicycle. This research focused on conceptualizing on different mechanisms for bicycles and then developed the selected concept and modelled it for possible marketing and production. The zero-carbon emitting bicycle can introduce an effective and sustainable means of transportation for porters and service personnel at airports while contributing to the elimination of the various other pollutants.

2. Background and literature review

Over the years, the use of transport has accelerated, and the world has seen a lot of advancement through technologies in terms of transport. Bicycles were founded over two hundred years ago and have consistently been improved. In 1817 a German scientist, Barn Karl von Drais invented the bicycle which had a typical frame and two wheels but was propelled by walking [8]. However, these bicycles did not have the aerodynamic speeds compared to the current bicycles, since there was no means of transmission such as gearing transmission [9]. Many engineers looked into this design and found it possible to improve from Drais' innovation. Up to now a lot of technologies have been used in order to improve bicycles, one of them being the electric bicycle. Although a lot of great bicycles have been invented and designed, there are still a lot of things that can be improved on the current bicycles. Most current bicycles which are in use today require a lot of human effort in order to cycle and this is a setback for convenient use as most of the energy has to come from the chemical energy stored in human muscles. Due to much effort required people end up preferring motor vehicles which require the use of fuels but damaging to the environment through pollution [10]. The use of hybrid energy can be a very pivotal turn around in the use of bicycles as they can improve efficiency and power required in order to drive a bicycle. There is need to look at the current bicycles' efficiency in order to improve it. There is also a need to look more into the gearing transmission, aerodynamics and also the hybrid energy in order to improve the efficiency and average cycling speed. There is also need to work on the safety of the current bicycles in order to reduce risk of injuries as it is one of the setbacks during travelling in main roads.

Bicycle aerodynamics is the most important aspect to look at if an efficient and reliable bicycle is to be designed or produced. This is one of the major reasons why bicycles require a lot of effort during cycling. The major aerodynamic resistance is air drag which increases with velocity of the bicycle [11]. Air resistance is the major force that helps retard the bicycle during cycling [12]. Apart from air resistances there are also other forces that act on the bicycle which hinder its movement and therefore resulting in much effort being required during cycling. These forces include rolling resistance, bearing friction, weight of the cyclist and also weight of the bicycle. By looking into the bicycle equipment and being innovative the effort required to cycle can be minimized [12]. Fig. 1 shows forces that act on a bicycle. Congested cities such as in China and India have battled with challenges of thick fog due to pollution and excessive construction of road infrastructure. However, they are gradually progressing towards sustainable cities by taking a leaf from similar congested cities such as Amsterdam that have embraced the use of the bicycle as a sustainable means of transportation [20]. In addition, they have also restricted the use of private vehicles by introducing road tolls [20].

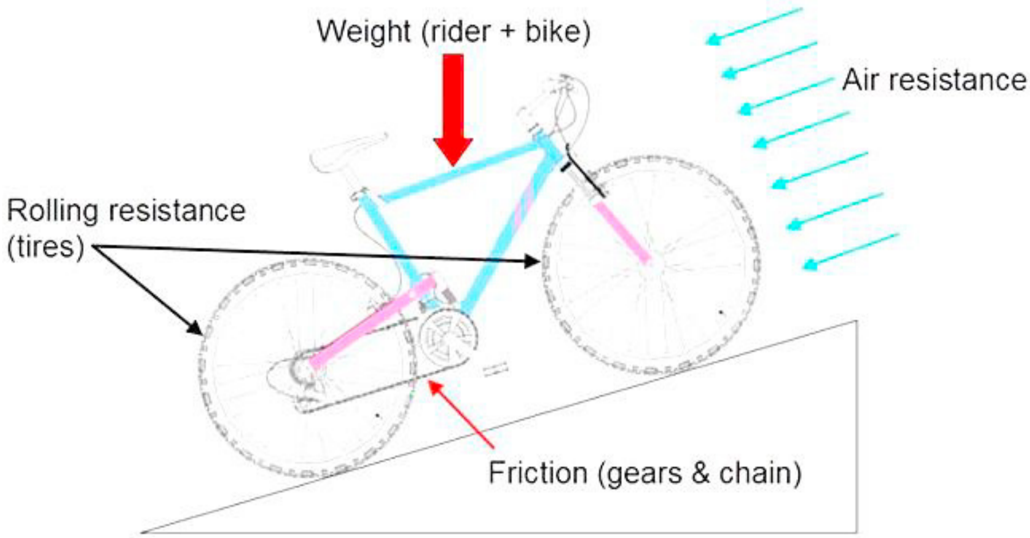

Fig. 1. Forces acting on a bicycle

3. Research methodology and materials

A research on electric bicycles that currently exist on the market worldwide was carried out in order to understand the anatomy of the electric bicycle. Common components of the electric bicycle were looked at in order to understand how they function and also establish their shortfalls. Further research was done on different drive mechanisms of electric bicycles. Data and information were gathered from various sources including journals, textbooks and magazines. Various data parameters were collected from sources such as text books and the internet. In order to come up with a safe design that met the objectives, these parameters were used as the starting point for the design calculations. The design calculations were performed on every component that made up the bicycle system. AutoCAD 2015 and Solid Works 2015 were used for the drawings and 3D modelling of the design. Solid Works 2015 was also used for performing stress analysis on critical components such as the planetary and rear wheel differential gears.

4. Conceptualization of alternatives

After carefully analyzing the information obtained from literature, three possible alternatives were generated to satisfy the research objectives. The advantages and limitations of each concept were analyzed in order to come up with and develop the optimal and sustainable solution. The binary dominance matrix [13] was used for concept rating and the optimal solution was selected from the three possible concepts.

4.1. Concept 1: Flywheel

In this concept the transmission gearbox was located in the same axis as the sprocket [11] with the motor parallel to it. The output from the electric motor was conveyed to the transmission system through a belt as shown in Fig. 2, modelled using Solid Works. Mounted to the frame of the bicycle was a flywheel which was used to store kinetic energy [14] when the rider decides to slow down. The energy stored in the flywheel is used when the rider feels like pedaling [15]. When the rider slows down or apply brakes the flywheel is engaged through a clutch system and it quickly rotates thereby storing energy. When the rider increases the speed of the bicycle, the flywheel [6] releases energy which is used to propel the bicycle [16]. The advantages of this solution are that higher efficiency is achieved due to the automatic transmission and more energy from the flywheel is added to the drive train.

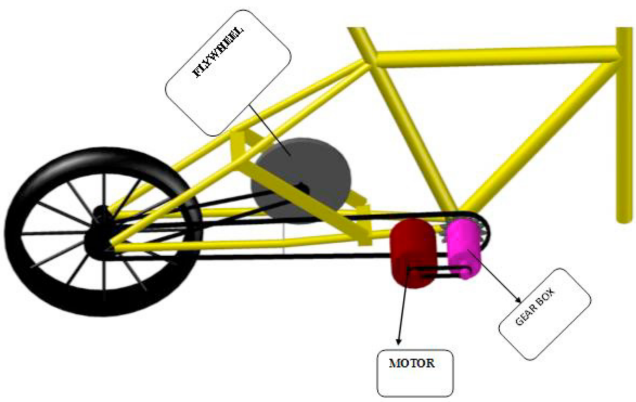

Fig. 2. Flywheel concept

4.2. Concept 2: Dual power system

Fig. 3, also modelled using Solid Works represents a concept with a dual sprocket in order that both power from the pedals and electric motor can be supplied to the rear wheel. This setup included a ratchet system which allowed motion in only one direction. This was done so that the pedals will not be driven by the motor

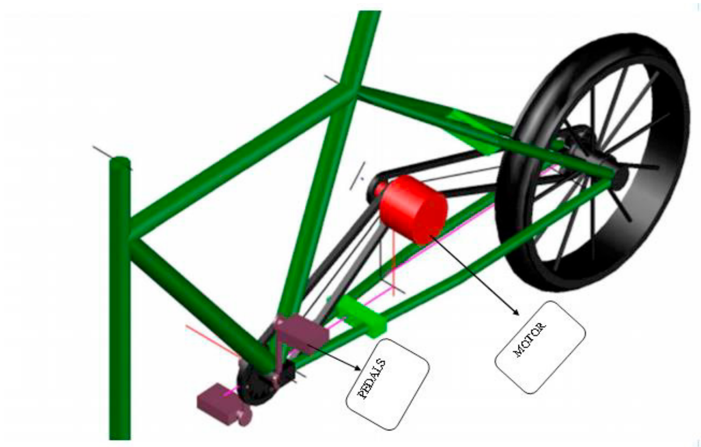

Fig. 3. Dual power system

4.3. Concept 3: Variable speed transmission

Fig. 4, also modelled used Solid Works shows the third concept which consisted of a drive shaft rather than a chain drive. Power was transmitted to the rear wheel through this shaft with a pair of bevel gears meshed at right angles located at each end of the shaft [17]. This setup also employed a Continuously Variable Transmission (CVT) which acted as an engine for the bicycle. The CVT offered the bicycle variable speed ratios which was achieved by the changes in pulley diameters that occurred in the CVT unit, the power of which was supplied by an electric motor. The advantages of this concept were that it achieved variable speed ratios due to change in diameter of the pulleys. It also provided maximum torque, quick acceleration and hence smooth ride.

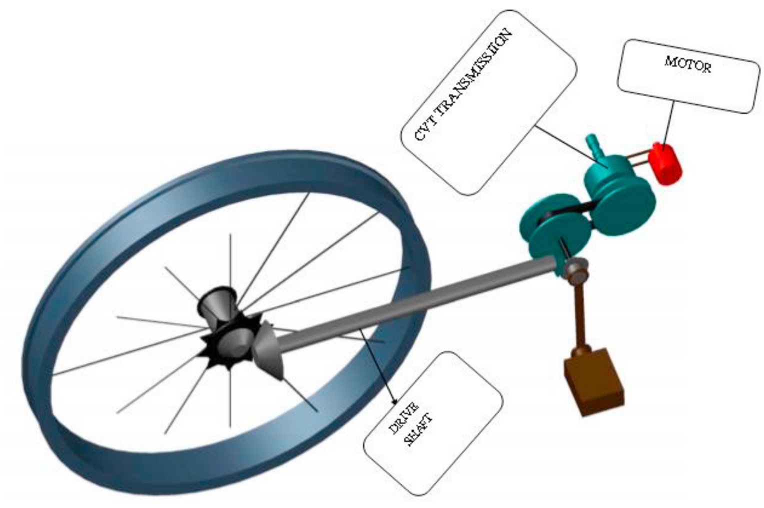

Fig. 4. Variable speed transmission

5. Model of operation and development of selected concept

The binary dominance matrix is a technique that is commonly employed by product development engineers to evaluate the most optimal solution or product from a variety of alternative ones [13]. It normally consists of a matrix developed from a set of criteria. In the case of the 3 concepts, the selection was based on the one which provided the best efficiency, least cost, ease of manufacture and maintenance, life span, weight and general appeal or aesthetics. The points allocated to each of these criteria were on a relative scale which were then multiplied by the importance or weightings of each criteria as shown in Table 1. Finally, the total weightings were summed up to select the one with the highest weighted objective. After a careful analysis of the three possible concepts and comparison of the different criteria and the total weighted objectives, the third concept with variable speed transmission and a total score of 257 was selected. A detailed design of all the components was performed and the stress analysis on the weakest parts carried out.

Table 1. Concepts and weighted objectives derived from the binary dominance matrix

		Criteria	Weight	Ergonomics	Efficiency	Lifespan	Ease of Manufacture	Assembly	Maintenance	Aesthetics	Retrofitting	Total Score
Concept		**Weight**	5	4	5	6	4	4	3	1	2	
	Rating	(1)	8	7	7	7	7	6	8	7	7	
		(2)	7	8	6	7	8	6	8	6	7	
		(3)	7	9	8	8	7	5	9	9	7	
	Weight	(1)	40	28	35	42	28	24	24	7	14	**242**
		(2)	35	32	30	42	32	24	24	6	14	**239**
		(3)	35	36	40	48	28	20	27	9	14	**257**

The power output from the motor was fed into the system through the sun gear of a planetary gear set inside the CVT transmission as illustrated in Fig. 5. A clutch plate is engaged and locks with the ring gear of the planetary gear set. This set then rotates as a single unit achieving forward transmission. The motion is then transferred to a set of front bevel gears where transmission is further stepped up. This transfer takes place through two conical pulleys which are able to shift the velocity ratios infinitely (Continuously Variable Transmission) by changing their effective diameters. The motion is then transmitted to the rear wheel differential gear through a shaft where it is further fed into the wheels resulting in motion.

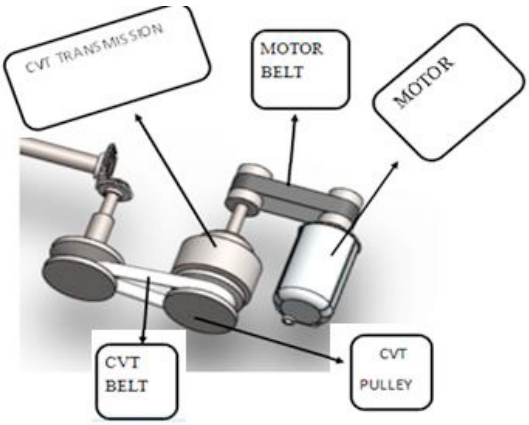

Fig. 5. Continuously variable transmission

6. Results

Comparison between a conventional bicycle and the designed bicycle was carried out and the average speed for cycling in conventional bicycles was determined to be about 4.36m/s. The desired speed of the designed bicycle was 8.33m/s. The time taken by each bicycle for different distances was compared and graphs of distance against time plotted in order to come up with a comparison. For each bicycle, Fig. 6 shows the results of distance and time calculated using the formula $t=D/v$ where D, v and t seconds are distance in m, velocity in m/s and time in seconds respectively.

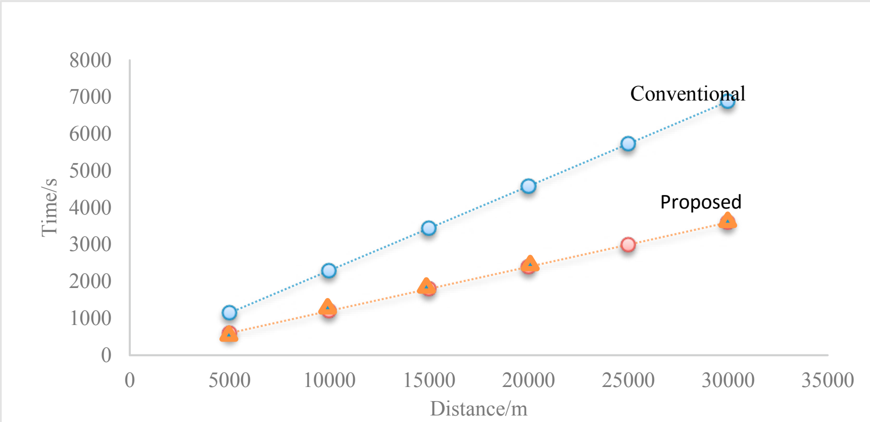

Fig. 6. Graphical comparison of the conventional and proposed design

7. Discussion and recommendations

Fig. 6 shows the plotted results of both bicycles from where it can be seen that for the same distance, time required by a conventional bicycle is almost double the time required by the new design. This result shows the necessity of the new design since it is more reliable. A rider would take less time with the new design than the conventional bicycle. This further addresses the improvement in efficiency and reliability accompanied by the new design. In order to interchange between human cycling and electric motor assist, an automatic way of engaging and disengaging the motor should be employed rather than switching on and off of the motor on the selected continuously variable transmission proposed for the new design. This will improve the convenience and reliability of the bicycle. Controllers and sensors can be incorporated as a way to enhance the use of the proposed design. The key aspect on the continuously variable transmission design was its ability to change the diameters of the input and output pulleys so that it was able to achieve an infinite number of speed ratios. An electro-pneumatic pump system can be used to achieve this. Energy storage is a very important aspect of the electric bicycle as it provides a way of powering the electric motor. Battery technology should be continuously improved in order to come up with convenient energy storage. A further research on super capacitors can be carried out as they can be used for energy storage in electric bicycles due to their high efficiency and also high energy density. Cyclists in most Southern African countries use the same lanes as motor vehicle operators. This exposes them to dangers and risks from these vehicles particularly in highways and busy roads. There is need to consider construction of established cycle tracks in order to minimize such risks. The issue of head injuries and other potential hazards emanating from the high speed were taken aboard in the overall design. The use of appropriate safety helmets and jackets was recommended to enhance safety of the rider. Although this new bicycle design entails sourcing a large number of batteries, the production and marketing of these would be an opportunity for vendors in the supply chain. However, this may pose a challenge in disposal. A clear outline of the product life cycle of the battery was developed to cater for cleaner production.

8. Conclusions

There is an increase in the awareness for the need to cut down on greenhouse and carbon emissions which are usually a result of fuel powered engines. This prompted the need to develop sustainable transportation systems that are free from pollution, in order to protect the environment and dangers of climate change. The use of electric and solar powered vehicles has gradually gained momentum but the biggest challenge to the generality of the populations around the world is affordability. This research focused on analyzing available options for an improved version of a bicycle over the conventional one, in terms of several criteria such as efficiency and ease of manufacture and maintenance. The selected design, the continuously variable transmission was analyzed and developed further and is proposed as a sustainable means of transportation. For stability and safety, a tricycle version of the concept is recommended. Although it will cost more than the conventional bicycle, the developed electric drive train provides a 'green' and affordable means of human transportation as well as protection of the environment from the dangers of climate change and increased emissions from fuel powered vehicles and factories. Further analysis and improvements can be carried out to enhance the design through the incorporation of controllers and sensors.

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