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# Bicycle Improvement: Flexible Electric Motor System

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***Abstract*: This paper is an educational design course project on the modification of a bicycle frame and engineering components to enhance mobility and reduce effort while cyclic.**

***The project was simulated with computer aided software which includes material selection and structural modification, which is an important element of design. The brushless DC motor is assembled over the back wheel as propellant. The correlative material/application processes and materials selection are briefly discussed in this study.***

***Keywords: Electric bike, Material selection.***

## I. INTRODUCTION

Motorized bicycles have seen increasing use as complete designs and as add-on motor kits are constantly being developed for use on standard bicycles. With new battery technology the use motors for power assist is increasingly popular, often using hub motors to facilitate after-market conversions. Converting bicycles or tricycles has proven useful for some people with physical disabilities such as knee injury or arthritis. Papua New Guinea (PNG) has a mountainous terrain cycling can be a very exhaustive activity as riding up slopes frequently can easily exhaust the cyclist.

This paper therefore aims to develop a flexible and adaptive motor train system which can be mounted onto any mountain bike frame which meets our model criteria and specification, hence, converting them into motorized mountain bikes.

## II. LITERATURE REVIEW

Complete Electric Bicycles are completely powered by the motor without aid from the cyclist [1]. They have the regular frame of a bicycle, but others have very specific aerodynamic design to reduce power consumption thereby increasing running time of the bicycle before further recharge [2]. While the traditional Bicycle require the Installation of conversion kit [3] and the motor only works when activated or needed. Motor can be switched on temporarily to aid the cyclist while pedalling. With the traditional model, positioning the motor can be quite tricky especially for non-technically inclined users as it requires use of tools to mount the motor at the lower corner where the down tube and seat tube meet [4].

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This part is chosen because it is the most stable position to hold and keep in place a motor. In order to achieve that, some accessories of the bike such as the water bottle and its holder must be removed.

The attached motor is arranged such that a separate chain connects to the rear wheel hub to the sprocket. Other designs place the motor with the pedal axel (mid-drive motor). This is usually done on dedicated frames designed to accommodate the motor and as such they are not flexible. In such systems, the motor sits under the pedal axel and lies parallel with its axis. The motor is powered by battery attached on the bike frame while switching and control is usually accomplished by a convenient electronic control module attached to the steering bar. The motor connects with the pedal axel by two spur gears in constant mesh. Ideally, the pedal axel pinion has a bigger diameter than the motor gear [5]. While in idle state, the motor rotates freely cycling until when it is engaged, in which case the motor turns the pedal axel and drives the bike. In advance systems, a torque sensor detects the riders torque output and only turns on when it falls below a certain value.

Most recently advances in technology enables manufactures install motor at either the rear or front hub of the wheels. These types of motors are called hub motors.

## III. METHODOLOGY

Our design is based on the standard bicycle frame which comprise of an extended seat-stay and chain-stay with the seat-stay having a gentler slope and the seat-tube housing the seat-binder is higher and horizontal with the steer (refer to figure 1).

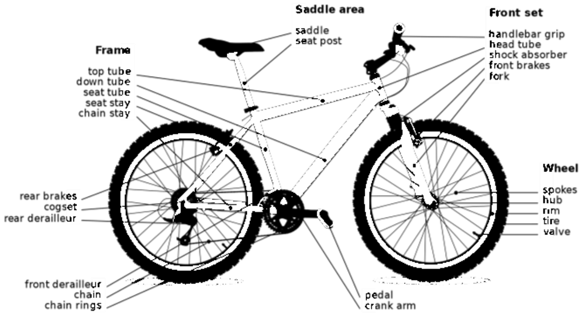

**Fig. 1.Bicycle anatomy**

The design implements a flexible and adaptive motor train system over the rear wheel for direct chain drive system vertically down to bicycle sprocket. The current add on motors are brand and model specific therefore they cannot be used in generic bicycles. The design is intended to assist biker surmount steep slopes with ease.

In analysing the dynamics of uphill cycling at constant speed, several factors affect motion dynamics which includes but not limited to rolling resistance, required torque, weight, frictional force, etc. refer to the diagram below.

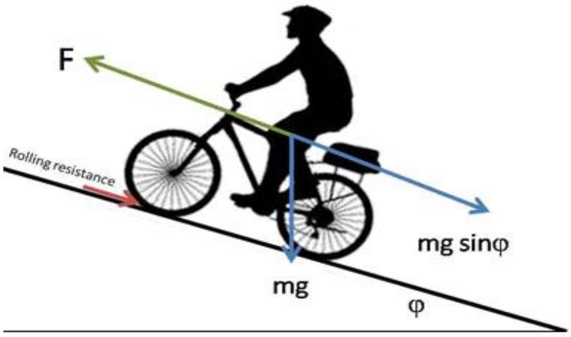

**Fig. 2.Forces acting during inclined motion**

Here, the weight factor of the system (mg) yields two retarding force elements that act to keep the cyclist stationary and/or roll down the slope. One of the factors is the rolling resistance, which is exerted by the surface on the tires to impede rolling motion. It is proportional to the slope angle (θ) and weight factor [6] and is related as:

$$\text{Rolling Resistance} = Crr * m * g * \cos(\theta) \tag{1}$$

where Crr is the coefficient of rolling resistance

In analysing force required to sustain the cyclist in constant velocity motion, the interacting forces are assumed to be acting at a central point, which is the designated centre of gravity (cg) of the system which may slightly vary with the weight and posture of the rider. However, an intrinsic consequence of all modern bike frame designs is that they are designed such that the cg is directly over the pedal and near the rear wheel [7]. This increases riding efficiency as riders weight impose more force on the pedal.

## IV. ANALYSIS

In motor sizing, the power and torque requirements were analysed using mathematical model for cycling power calculations developed by Martin Milliken [8] while working at the Institute of Applied Biomechanics in Massachusetts, USA.

$$p_{total} = \frac{p_{AT} + p_{KE} + p_{RR} + p_{WB} + p_{PE}}{E_c} \tag{2}$$

Also, given that a 24-inch wheel was selected (radius 13”), the torque and power relations is given by

$$P = FV_g = Tw_w = T\frac{V_g}{r_w} \tag{3}$$

$$w_w = \frac{V_g}{r_w}$$

$$N_w = \frac{w_w \times 60}{2\pi} \tag{4}$$

$$N_m = N_w \frac{r_{ws}}{r_{ms}}$$

From these calculations we can specify the motor requirements for the given scenario [9]. Therefore, a 1500W low rpm motor (high torque and power output) was selected.

However, from the theoretical calculations, the maximum slope for a system mass of 90 kg is 30º.

## V. MATERIAL SELECTION & PROPERTIES

### A. Shaft assembly

The motor was mounted on the designed shaft assembly used to hold the rack in place. It is attached to the seat post and the rack using universal joints and clamps which is designed to be strong enough to withstand the opposing forces pulling the rack seat post apart, withstand fatigue, considerable shock and weather resistant hence brass was selected [10].

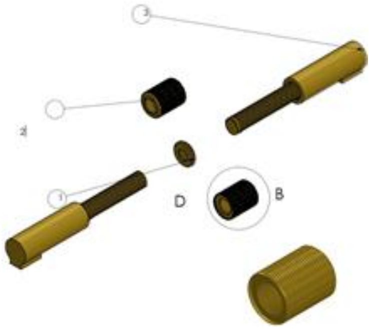

**Fig. 3.Shaft assembly**

### B. Rack

The rack is connected to the seat post via the shaft assembly and is supported on the axle of the rear wheel of the bicycle and it is made with 1060 aluminium. This is due to the shock loading from the rear wheel and the expected vibrations and heat under normal working condition [11].

**Fig. 4.Rack design**

### C. Universal Joint Assembly

Universal Joint Assembly was used fix both ends of the adjustable shaft assembly to the rack and the seat post of the bicycle. Due to the reduction in area, the force acting upon this component will be significant value hence the major considerations were, weathering, fatigue and vibration [12]. Also, the fastener clamp is subjected to same conditions as the universal joint assembly hence, the ASI 304 stainless steel was the preferred selection as it has yield strength of approximately 206.807MN/m$^2$ [13] thus no plastic deformation or failure is expected upon application of a load of 900N.

(a) (b)

**Fig. 5.(a) Universal joint (b) fastener clamp**

### D. Motor Casing

This protects and houses the motor hence it should be vibration resistant, weather resistant to protect vulnerable motor parts from corrosion and weathering as well as light.

Acrylonitrile Butadiene Styrene (ABS) [14] which is a thermoplastic exhibits the desired characteristic and was thus chosen as an ideal inexpensive material for the motor casing material.

**Fig. 6.Motor casing design**

**Table 1: Material summary**

| | Type of Part | Material |
|---|---|---|
| 1 | Adjustable Shaft Assembly | Brass |
| 2 | Rack | 1060 Aluminium Alloy |
| 3 | Universal Joint Assembly | ASI 304 Stainless Steel |
| 4 | Motor | Copper Austenite Iron |
| 5 | Fastener & Drive yoke | ASI 304 Stainless Steel |
| 6 | Motor Casing | ABS Thermoplastic |

## VI. DESIGN EVALUATION

The bike frames are designed such that the rider and the bike centre of gravity are approximately over the pedal. This is to make the rider's weight part of the force applied to the pedal and as such reduce muscle work. However, with the addition of the motor, the centre of gravity slightly moves backwards which may pose risk when ascending steep slopes this however can be reviewed in further works.

Furthermore, the design of the rack and other components are based on being the link between the motor and the bike frame. These components may experience, gradual decline in performance and geometrical profile after some cycle of use due the technique employed in manufacturing of the components.

Vibrations may also affect chain tension; hence the use of an idler pinion attached to a spring-loaded arm fixed to the motor casing to prevent the chain from getting loose.

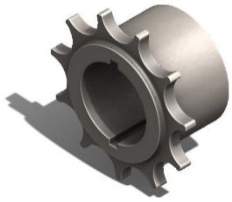

**Fig. 7.Motor sprocket**

**Fig. 8.Holding joint**

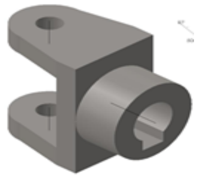

**Fig. 9.Driving yoke**

Having a yield strength and Tensile Strength as indicated coupled with the dimensions of our designed rack; it will be able to withstand fatigue from the shaft assembly and from the wheels as indicated in the simulation diagrams below (Without exceeding limits).

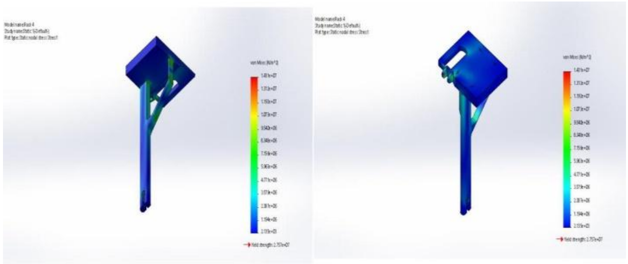

**Fig. 10. Rack stress simulation**

## VII. CONCLUSION

Mechanical engineering students were motivated to investigate the design of a bicycle project as a challenge to improve creativity. Evaluating creativity outcome is a valuable part of design education as it encourages conscious effort towards creative thinking and innovation.

Thus, the details showing the design and simulation of the electric bike have been discussed. The wheel hub added has also been calculated and suitable material was selected to aid efficiency while improving dissipation of heat and performance of the bike. The results obtained are without further modifications of the initial design. However, further improvements could be achieved by redesigning some of the components as described in the paper.

**Fig. 11. Assembled bike**

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