FRONT, MID AND READ DRIVE COMPARISON OF AN ELECTRIC BICYCLE USING E-BIKE CONVERSION KITS ON A CIRCULAR ROUTE

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Abstract

The goal of this paper is to present the testing procedure of an electric bicycle for the purpose of selecting the most suitable drive for a hotel resort chain e-bike fleet. The testing procedure comprises of installing e-bike conversion kits on a single standard mountain bike type bicycle and testing each separate drive on the same route with the same driving profile. Three different drives are needed, front, mid and rear section drives. Different drives were assessed based on their power, torque, traction, range, acceleration, road incline capability and most importantly the overall tester's feel of the drive. The kit selection process was based on purchasing drives with the same voltage and power rating, the only difference being the gear ratio of each drive type. The drive kits come with LCD screens, throttle, pedal assist sensors, breaking handles with position signals, motors with spokes, rims and their accompanied drives and most importantly their battery packs. The battery packs have a rated voltage of 48 V, the capacity of 16 Ah and the energy of 768 Wh. It is made using LG's 18650 type battery cells with 3,7 V and 3,2 Ah per cell, this makes a configuration of 13s5p. All three drives were installed on the same bicycle to equalise the mass of the bicycle on every test. For the most accurate measurement the tests need to be conducted on a safe and secure route without any traffic, thus a velodrome was chosen for this purpose. The measuring equipment consists of high frequency GPS and accelerometer modules along with a smartphone application to calculate the vehicle dynamics model and were processed in a LabView environment. The vehicle dynamics model was calculated and plotted in the Matlab simulation environment.

Keywords: electric bicycle, e-bike, conversion kits, hub drive, mid drive, battery, velodrome

1 Introduction

With the rise in popularity of electric vehicles and electric mobility in general, electric bicycles have also flooded the market and become a sought out product. Their functional advantages over conventional bicycles in the form of speed, acceleration, and reduced effort can enable people with physical limitations or time constraints to take up or continue cycling, and they can enable cycling for more trips, overcoming barriers such as distance and weather [1]. This paper began as a research project aimed at finding the most suited and cost effective electric bicycle for hotel resort guests' use [2]. The focus I mostly on seaside resorts along the Adriatic coast. With to development of cycling infrastructure, riding regular or electric bikes has become more popular [3]. Since, for most tourists transporting their bicycles to their vacation destination would be inconvenient, an electric bicycle fleet on offer by the hotel resort seems like a good option. It would stand to reason that riding electric bicycles would be even more appealing to tourists than regular bicycles due to ease of use and it being less straining at longer routes or harder terrain.

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2 Choosing bicycle type and components

2.1 Choosing the bicycle type

One of the most important factors taken into account when picking a bicycle and its parts is the riding terrain and its layout [4]. In this case the terrain is ranging from flat paved roads and walkways to more sloped and bumpy forest trails and walking paths. For this terrain type a classic mountain bike was chosen and can be seen on Figure 1. The mountain bike frame is medium size, has front suspension forks, rim brakes and off-road tyres.

Figure 1 Chosen mountian bike

2.2 Choosing the e-bike conversion kits

Test bicycle is fitted with three different electric motor propulsion system [5]. They differentiate in part of the bicycle they deliver power. Two of them are hub motors installed in wheels, one in the front rim and other in the back rim and they deliver power through wheel spokes directly to the ground, they are mechanicly independent from pedal actuated power delivery system. Middle motor propulsion kit uses bicycle's chain to deliver power to the wheels. The same batteries are used for every and their characteristics are shown in Table 1.

Table 1 Battery characteristics

Cell type	**Voltage** [V]	**Capacity** [Ah]	**Energy** [Wh]	**Mass** [kg]
LG 3200	48	16	768	4

2.2.1 Front and rear hub motor kits

Front and rear motors have the same rated nominal power of 750 W and rated voltage of 48 V. Kits consist of a 26 inch rim with integrated hub motor, DC/DC converter with integrated controller, brake levers with an integrated shut-off switch, Pedal Assist System, LCD screen and throttle as shown in Figure 2 [6].

Figure 2 Front/rear hub motor kit [6]

2.2.2 Mid drive motor kit

In the mid drive motor kit the controller and converter are both integrated in the motor housing and are shown on Figure 3 [7]. The motor has a 44 tooth gear connected directly to the output shaft that drives the chain. The rest of the components are identical to hub motors kits except for an extra wheel speed sensor.

Figure 3 Mid drive motor with 44 tooth gear and cranks [7]

3 Installation

3.1 Conversion kit installation

All of the kits come with certain parts that are mounted on the bike the same way regardless of which kit it is. New brake levers have to be installed on the bike instead of the old ones. The brake levers come with an extra switch that cuts off power to the motor if the brake lever is engaged for safety purposes. LCD screens are mounted in the middle of the handle bar. Throttle control is mounted on the steering wheel. Twist throttle is mounted instead of the handle grip while the thumb throttle is mounted right behind the grips as it is much smaller. The battery mounting plate is screwed into the water bottle holder mounting spot. All of the components and connecter to the controller via cables included in the kits. The bicycle with all kits is shown in Figure 4.
Not all parts of the kits need to be installed in order for the bicycle to be functional as an e-bike. The motors can be controlled using only a pedal assist sensor so the throttle doesn’t need to be installed.

Figure 4 Electric bicycle with all kits and test equipment installed

3.1.1 Front hub motor kit

The front wheel hub motor kit was the easiest one to install on the bicycle. First the front brake was disengaged so the old front wheel can be removed. The old tyre was transferred to the new rim that is attached to the motor. Then the new front wheel was put back on the bicycle and the brakes engaged again. The cranks had to be removed in order to mount the pedal assist sensor and then put back again. This required a special tool that can be bought in bicycle stores.

3.1.2 Rear hub motor kit

The rear wheel hub motor kit requires the same process as the front kit but with one extra step. The cassette has to be transferred from the old rim to the new one. For this step the rims were taken to a bike repair shop and the cassettes were transferred in a few minutes.

3.1.3 Mid drive motor

For the mid drive motor kit there is no need to remove the wheels because the motor and the controller are located in the lower middle part of the frame. To mount the motor and controller the cranks and the middle gears and hub have to be removed. New cranks are already mounted in the mid motor itself. Since the motor speed doesn't always correspond to the same wheel speed due to the changing gear ratio, a wheel speed sensor needs to be mounted on the frame next to the rear hub and a magnet on one of the rear wheel spokes.

3.2 Sensors and measurement devices

"PhidgetSpatial Precision 3/3/3 High Resolution" accelerometer and "PhidgetSpatial GPS" GPS module were used to measure bicycle speed, position and acceleration over time during the test. All the measurements were processed and logged using the LabVIEW programming environment. For comparison the same measurements were recorded using the "My tracks" mobile phone App. Bicycle dinamics calculations were done using MatLab programming environment. To record all the information provided on the bicycle LCD screens during testing a mobile phone camera was used. To mount the phone above the screen a plastic box was 3d printed and mounted on the screen. The box has a mounting point for a mobile phone on top. The inside of the box is sealed from outside light so the screen glare doesn't affect the visibility.

4 Test and results

Electric bicycle testing took place at a local velodrome in Zagreb shown in Figure 5. The faculty was granted permission to use the velodrome for four hours for free. The velodrome was picked so the bicycle can be ridden uninterrupted for a long period of time. Also, because of all the equipment and wires installed on the bicycle it would be safer for the testing rider not to drive on the road or walkways. This velodrome is on the open (outdoor) and the test was being carried out on a hot sunny summer day from 12 to 16 hours in the afternoon. When it comes to overheating and sun exposure this was around the worst case scenario. Since the velodrome was available for only 4 hours all 3 kits were simultaneously installed on the bicycle, but used one by one. The weight of the bicycle with all the kits and equipment was 36 kilograms. Rider riding the bike during testing was weighing in at 100 kilograms. This way all the conditions can be considered as worst case scenarios. During the test the bicycle was propelled using only the throttle. The rider did not turn the pedals during the test. The batteries were charged to full before testing and the bicycle was ridden on full throttle until all the charge in the batteries was depleted. This was repeated for every kit.

Figure 5 Velodrome

4.1 Front and back hub motor kit

Since both motors are essentially the same except for being mounted on different wheels, the rider covered a distance of 51.5 kilometres in 90 minutes. The maximum speed slowly decreased during the test from 38 km/h to 31km/h as shown in Figure 6, Figure 6with the average speed being 34.3 km/h. The battery was quickly removed from its case at the end of the test and was only warm when touched. Considering the harmful temperature threshold of the battery cells is 60 degrees Celsius, the battery performed well within its temperature limits. The power graphs can be seen in Figure 7. The oscillations in power are caused by turning on the velodrome. On curve entries the bicycle slows down slightly and on exits it accelerates.

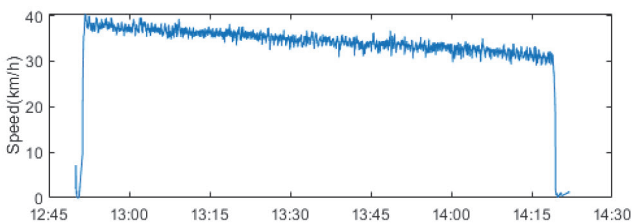

Figure 6 Speed graph for front hub motor kit

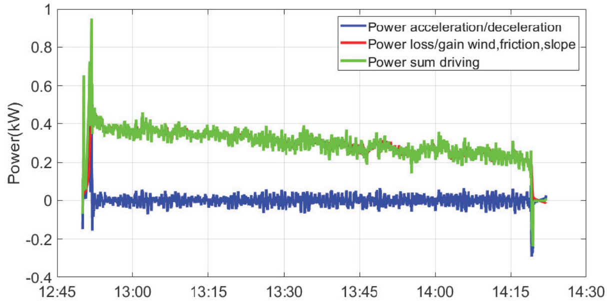

Figure 7 Power graph for front hub motor kit

4.2 Mid drive motor kit

The mid drive motor kit managed to cover a distance of 40.7 kilometres in 63 minutes before the battery was depleted. The maximum speed slowly decreased from 42 km/h to 36 km/h as shown in Figure 8, with the average speed being 38.8 km/h. The bicycle was ridden in the highest gear to be as efficient as possible at higher speeds. The motor used more energy but propelled the bicycle 4.5 km/h faster on average than the front and back hub motor kits. The battery was quickly removed from its case at the end of the test and was warmer to the touch than in the previous tests, but still within the safe temperature. The power graphs can be seen on Figure 9. Oscillations are caused by the same reason as with front and rear motor kits.

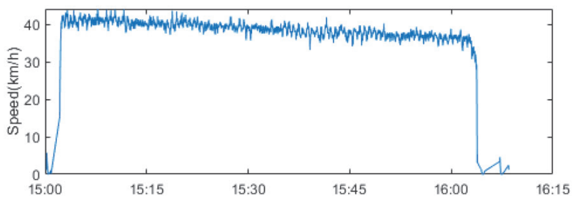

Figure 8 Speed graph for mid drive motor kit

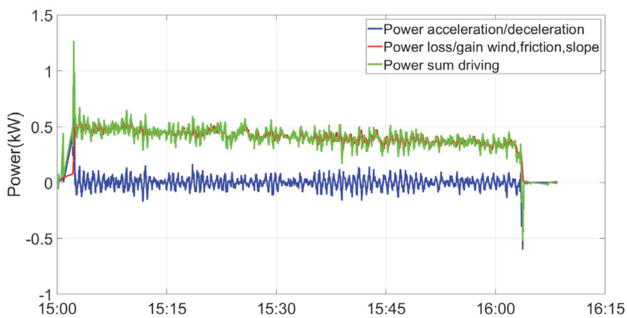

Figure 9 Power graph for mid drive motor kit

5 Conclusion

After testing all three electric bicycle conversion kits a decision on which kit is the most suitable for this application was made. One additional factor that needed to be taken into account is the price. When compared, without the battery, the mid drive kit is three times more expensive than the front or rear drive conversion kits. The test result show that the mid drive outperformed the front and rear drive kits. It is more versatile due to the fact the rider can adjust the gear ratio of the motor while the front and rear drive kits directly drive the wheel. Although the mid drive conversion kit proved to have better performance, the front and rear drive kits performed better than expected considering the price. When ridden in pedal assist mode they are more than capable of overcoming medium inclines that would be hard for a casual rider on a normal bicycle. When comparing front and rear drive kits a slight advantage was given to the rear drive kit due to the rear wheel taking more load, especially when going uphill. The front drive kit was prone to lose traction on the front wheel when ridden on slippery or dusty surfaces. The rear wheel drive conversion kit was chosen as it delivered good performance for a low cost. If the mid drive kits were to become cheaper in the future they would become the number one option.

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