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Development of Two Wheel Drive Electric Bikes for Extreme Road and A Long-Range Capabilities

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Development of Two Wheel Drive Electric Bikes for Extreme Road and A Long-Range Capabilities

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Abstract. This paper aims to develop the electric bicycle by using a two-wheel drive that has a long range of use. This development is motivated by many extreme roads and the absence of a charging station except in the user's own house. A folding bicycle type bicycle for adults with 16-inch wheels was used in this study. The two-wheel drive can be adjusted using the driving motor to be more flexible and adapt to road conditions, although the motor power used is small, 350-Watt 24 Volt for one wheel. The battery capacity used is quite large for the range quite far away, which is 24 volts 80 Amps, and the charging time is about 2 hours. The placement of the battery has calculated the center of gravity and balance of the bike. Results show that this electric bicycle can be used for slippery road conditions and slopes of not more than 1A maximum speed of the bicycle can reach up to 30 km/hour, on flat road conditions. Likewise, the bicycle's range for a full charge is around 220-260 km, with an average speed of 15-16 km/hour. Two drives can be implemented independently, adjusting the running conditions by moving the drive motor selection button. For extreme conditions, it is recommended to use two electric motors.
Keywords: *Electric, Bicycle, Two-wheel drive.*

1. Introduction
Electric vehicles are a priority for future vehicles with the decreasing reserves of petroleum and fossil energy. Innovation and development of electric vehicles is a necessity and a necessity for the future. The trend of electric vehicles as electric vehicles is also getting stronger in a number of developed and developing countries. Presidential Regulation No. 55 of 2019 concerning the Acceleration of the Battery-based Electric Vehicle Program, has been published in Indonesia.

Electric bike research conducted by Ali Ramadahn et al. [1], Sundhy Pareza [2] and Sunikhita et al. [3] discusses the application of electric bicycles related to environmental issues, smart electric bikes and eco-friendly and energy saving. More technical research, conducted by Benny Setiawan [4], Hendarto Putro et al. [5], Shweta Matey [6], Ram Bansal et al. [7], Hollandra Arif Kusuma et al. [8] related to the calculation of the maximum load that can be driven by a medium power BLDC electric motor with various electric power, such as front, rear and middle drive positions.

The battery is a very important component, especially regarding the determination of the battery capacity or range per one charge, the charging system and how to use it safely. Indah Susanti et al. 2019 [9], conducted an analysis of determining battery capacity and charging for this type of Lead Acid battery. Although for Electrical Vehicles now many have led to two choices of Littium Ion and Lithium Ferro batteries in particular. For more large capacities, users prefer to use the LiFerro type with several advantages for reasons of durability, safety, and battery capacity.

The design and fabrication of electric vehicle (EV) conducted by Jatmiko et al. 2019 [10] is quite interesting to be used as a reference for analyzing the performance and power consumption of the 350 W BLDC motor. The purpose of the design is to obtain a high-efficiency, energy-efficient vehicle (EV) performance. The results of this study can be used as a reference regarding the determination of the most efficient speed, high power with low consumption. Another interesting article to take an important point is the design and fabrication of a single-drive electric bicycle by Raka Pangestu 2018 [11], Ismail 2020 [11]. Likewise, several studies that examine harverting energy (Moch Edoward et al., 2016) [13], control systems for the efficient use of electric motors which become the next generation of e-bikes (Abagnale et al.) [14], (N. Pavan er al.) [15].

According to the e-bike research and study above, the implementation of the electric motor on the e-bike still uses one electric motor drive, low battery capacity and a short range of use, which is no more than 50 km for one time charging. Based on this, this paper explores and develops an e-bike with a long-range capacity with semi-heavy conditions with two electric motor drives. This design is tested on the ability to reach distance, speed and transport capability.

2. Design of Two Wheel Drive E-Bike, Torque and Power Theory

2.1. Design of 3D E-bike

A virtual 3D image of a two-drive e-bike can be seen as shown in Figure 1.

Figure 1. Virtual Design of 3D E-Bike Two Wheel Drive

The e-bike electric motor drive that will be implemented consists of an electric motor drive with positions on the front and rear wheels. The bicycle that will be used is a folding bicycle with 16 inch wheels for adults with a weight of about 75 kgf.

2.2. Torque and Mechanical Power

To calculate the thrust, torque and mechanical power of an electric motor, it is necessary to first find the total mass ($Mtot$) that will be driven by the electric motor. The total mass of the bicycle, including the battery, rider, and electric motor is 15 kg + 22.4 kg + 70 kg + (2 x 5 kg) = 117.4 kg or 1150.5 N. Then the normal force, static friction force, kinetic friction force and torque are approximate the formula can be described as follows.

$$N = Mtot \cos(\theta) \text{ x } 9.81 \quad (1)$$

Where: N is the normal force at a certain slope angle θ. If the bicycle is moving on a flat plane then N = $Mtot$.

$$F_S = F_N \ x \ \mu_S \quad (2)$$

Where: F_S is the static friction force, μ_S is the coefficient of static friction

$$F_K = F_N \ x \ \mu_K \ (0.6) \quad (3)$$

Where: F_K is the kinetic friction force, μ_K is the kinetic coefficient.

From the static and kinetic forces of the wheel radius function, the torque can be approximated by the formulas 2.4and 2.5.

$$T_S > F_S \: x \: R_{wheel} \tag{4}$$

$$T_K > F_K \: x \: R_{wheel} \tag{5}$$

Where: T_S is static torque, T_K is kinetic torque and R_{whe} is wheel radius.

The torque provided to move the bicycle must be greater than the static and kinetic torque in order to accelerate. Resultant Torque in rolling motion from zero velocity to a certain velocity and constant velocity is determined bythe magnitude of the rolling resistance coefficient at the bearing surface. Likewise, it is also affected by tire air pressure. The result of torsion in rolling motion in a flat plane can be shown as follows.

$$\sum T = I \: \alpha \tag{6}$$

$$T - F_r = I \: \alpha \tag{7}$$

$$T - 2 \: \mu_r \: N\theta \: r - W_{tot} \sin(\theta) \: r = I \: \alpha \tag{8}$$

Where: T is the resultant torque, F_r is the rolling resistance force, μ_r is the resistance coefficient, $N\theta$ is the normal force of each wheel at a certain plane angle, which is equal to $W_{tot} \cos(\theta)$, r is the wheel radius, θ is the angle of inclination of the road surface, I is the moment of inertia and is the rotational acceleration. If the bicycle has been at maximum or constant speed, then equation 2.8 becomes

$$T = 2 \: \mu_r \: N\theta \: r + W_{tot} \sin(\theta) \tag{9}$$

To determine the acceleration can use the equation

$$V^2 = V_0{}^2 + 2 \: (S + S_0) \tag{10}$$

$$a_x = (V^2 - V_0{}^2) \: /(2(S + S_0)) \tag{11}$$

Where: V is the instantaneous velocity, V_0 is the initial velocity, a_x is the acceleration, S is the instantaneous distance, S_0 is the original distance.
If it is assumed that the desired speed is 30 km/h covered over a distance of 40 m, then the acceleration is 0.87 m/s^2. Acceleration calculations can be carried out for several possible desired speeds from the condition the bicycle starts to move.
One important thing that also needs to be considered is the rolling resistance coefficient (μ_r), where this coefficient affects the thrust resistance. Determination of the rolling resistance coefficient (μ_r) which is assumed to be a linear function of speed, can use the following equation [16][17].

$$\mu_r = f_o + f_s \left(\frac{V}{100}\right)^{2.5} \tag{12}$$

Where: $f0$ is the basic coefficient and fS is the coefficient determined based on the velocity effect. The values of $f0$ and fS can be obtained from Figure 2 [16][17].

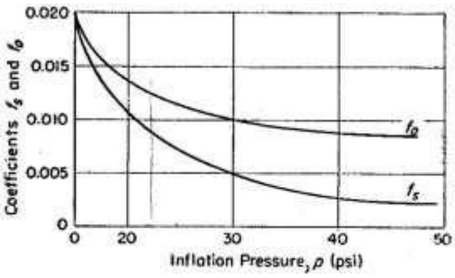

Figure 2. Supplementary coefficients f_0 and f_S for use in Equation 2.13 [16][17]

The calculation of electric motor power due to the required torque can use the following equation:

$$P = T\frac{2\pi n}{60} \tag{13}$$

Where: P is the mechanical power required to produce a certain resultant driving torque, n is the rotational speed of the drive wheels.

3. Results and Discusion

3.1. Calculation of Torque and Mechanical Power

Based on the above formulation, namely the equations 2.8, 2.10, 2.12, and 2.13, under conditions of 20 psi tire pressure and 16-inch wheel radius (0.203 m) then the results can be obtained a, μ_r, T, as shown in the following table.

Table 1. Torque Requirements per several final velocity levels

V_1 (m/s)	a (m/s^2)	μr	T_{Vo-V1}	T_{V1}, a = 0
30	0.87	0.01003	12.7	2.3
25	0.60	0.01002	9.5	2.3
20	0.39	0.01001	6.9	2.3
15	0.22	0.01001	4.9	2.3

The power required at each level of speed increase can be seen in table 2 below.

Table 2. Drive power requirements per several final velocity levels

V_1 (m/s)	a (m/s^2)	μr	P_{Vo-V1} (watt)	P_{V1}, a = 0 (watt)	P_{ave} (watt)
30	0.87	0.01003	520.8	96.2	308
25	0.60	0.01002	325.8	80.0	203
20	0.39	0.01001	189.8	64.0	127
15	0.22	0.01001	101.0	48.0	75

Notes: P_{Vo-V1} is power when V_0 to V_1; $P_{V1-a=0}$ is the power when a = 0
P_{ave} is average power based on maximum velocity

If tables 1 and 2 are observed that every increase in speed, the power also increases. From the results that the maximum average power requirement to reach a velocity of 30 km/hour, is 308 watts. Power requirements are very large when the bike is accelerating. Meanwhile, if the speed is constant or there is no acceleration, the power required is relatively low, namely a maximum of 96.2 watts.

The analysis above is based on flat road conditions and asphalt roads (hard roads). If the road conditions are sloping,using equations 2.8, 2.10, 2.12, 2.13 and 2.14, the maximum capability, torque, power and recommended speed are shown in the following table.

Table 3. Velocity, torque and maximum power at some angles of road slope

θ	V_{1max} (km/h)	T_{max} (Nm)	P_{max} (watt)
5^o	20	17.1	468.3
10^o	15	23.2	476.0
15^o	10	33.7	461.3

Note: using two-wheel drive (two electric motor drives)

The implementation of a two-wheel drive e-bike on an inclined surface of up to 15^o requires a power requirement ofbetween 461.3 watts to 476.0 watts, so it is recommended that electric bicycles use the option of two wheel drive, front and rear.

3.2. Electric Motor Determination

Brushless DC (BLDC) motors are the most commonly used motors for medium speed electric vehicles. This motor no longer uses a brush. If in a brushed DC motor, the coil acts as a rotor, in a BLDC motor, a permanent magnet acts as a rotor. The advantages of BLDC motors are good torque, high efficiency, have good resistance in long use, can work optimally in all rpm rotation ranges. But the weakness of the BLDC motor is that it requires a controller, limited top speed, and low power weight ratio. With the torque and power requirements for medium speed and road conditions with a maximum slope of 15 degrees, the motor specifications were chosen as shown in table 4 below.

Table 4. Specifications of the Electric Motor used

No	Specifications	Description
1	Type Motor DC	Brushless motor DC (BLDC)
2	Output Power	350 Watt
3	Voltage	24 Volt
4	Rate Speed	400 – 440 RPM
5	Max Electric Current	14.5 Amp
6	Weight of one BLDC Motor	5 Kg
7	Speed	25 – 35 Km /Hour
8	Wheel rings	14 and 16 Inch

If the motor uses two drives, it means that the total torque and power of the electric motor are doubled, with the same maximum speed i.e. 400 - 440 rpm. Utilization of two electric motors is used when heavy loads and incline conditions.

Based on the above calculations, it is recommended that the use of an electric bicycle for flat and constant speed roads is sufficient to use only 1 electric motor drive with rear wheel drive. Based on the power calculation above, if the bicycle is applied to a maximum speed with an acceleration of 0.87 m/s^2, and a maximum speed of 30 km/hour, then an electric bicycle is safer to use two drives. If the acceleration is 0.6 m/s^2 and the maximum speed to be achieved is 25 km/h, then it is enough just to drive an electric motor. Meanwhile, if using two electric motor drives and on some road slope conditions it is estimated to use 2 electric motor drives with the maximum achievable speed as shown in Table 3. For heavy field conditions and inclined planes, the recommended maximum power is 500 Watt, with two drives electric motor is applied.

3.3. Determining Battery Capacity

The LiFePO4 battery is the choice for use on this electric bicycle with a fairly large capacity specification, i.e. operating voltage 3.2 Volts, charging voltage 3.65 volts and max continuous current 80 Ah. The operating capacity of the battery is very stable, and is much higher in many usage ranges from 100% to at least 20%. Details of specifications and battery capacity with voltage adjusting the voltage and power of the electric motor can be seen in table 5 below.

Table 5. LiFePO4 Battery capacity

Battery Parameters	LiFePO4	
	1 cell 80 Ah	8 cell 80 Ah
Volt	3.2 -3.65 V	25.6 -29.2 V
Volt operation	3.26-3.54 V	26.1-28.3 V
Max Power per hour	292 Wh	2336 Wh
Power, 80% efficiency per hour	234 Wh	1869 Wh

A fully charged battery will reach 3.65V at the end of the bulk charge and absorption stages and be held in voltage until a disconnection current is reached (usually between 3-5% battery capacity). The charger will enter the float stage from 3.26-3.54V.

3.4. Battery Usage Time

The electrical energy stored in a battery can be recharged when the stored energy has been completely absorbed by the BLDC electric motor load. Battery discharging time can use the equation.

$$t_{\text{battery consumption}} = \frac{\text{Battery Capacity}}{\text{motor working current}} \tag{14}$$

If the number of battery capacity and motor current when working is, $t_{\text{battery consumption}} = \frac{80\text{ Ah}}{14.6\text{ A}}$ then $t_{battery\ consumption}$ = 5.48 hours. Battery de-efficiency 20% = 4.384 hours, so the effective mileage at 30 km/hour is 131.5 km. The mileage is close to 200 km if the average speed of the V1 is between 15 km and 20 km.

Table 6. Calculation of electric bicycle usage and mileage, with an electric motor BLDC 350Watt 24V, 14.6 A, maxvelocity 30 km/h.

$V1$ (km/h)	Electric motor power (Watt)	Electric current Amp.	Battery usage time (hour)	De-efficiency, 20% (hour)	Effective Usage Time (hour)	Mileage (km)
30	308.5	14.6	5.48	1.10	4.38	131.5
25	202.9	12.2	6.58	1.32	5.26	157.8
20	126.9	9.7	8.22	1.64	6.58	197.3
15	74.54	7.3	10.96	2.19	8.77	263.0

Consumption of electric power on electric bicycles can be done by calculating the use of batteries for BLDC electricmotors with an average velocity of 15 to 30 km/hour with a voltage of 24 volts with the assumption that the value ofthe electric current is proportional to the value of the bicycle's velocity.

3.5. Test Confirm Design and Performance

From the calculations and design concepts at the design stage, it is continued with the manufacture of a two-wheeldrive e-bike prototype as shown in the following figure

Figure 3. Prototype of two-wheel drive e-bike

The results of the prototype performance test as a confirmation test include maximum speed, ability on sloping roads and battery consumption and range of use. The speed of two-wheel drive in the performance test can reach 30 km/hour as can be seen in the following figure.

Figure 4. Velocity test on a flat road

The mileage test of the two-wheel e-bike was tested on the highway using the Reliev Application to measure thetravel distance, maximum speed and average speed, including measuring battery capacity.

Figure 5. Performance Test: mileage, maximum velocity, average velocity and battery consumption

Based on velocity and acceleration tests on flat roads, the following information is obtained.

Table 7. E-bike acceleration test

V1		Distance (m)	a (m/s^2)
Km/h	m/s		
26.8	7.50	35.2	0.79
27.0	7.50	36 .0	0.78
27.2	7.56	36.0	0.80

According to some experiments that every 10 km distance the battery will be reduced by about 0.1 volts. If the LiFePo4 battery usage range is in the voltage range of 26.1-28.3 V (see table 5), then the distance traveled will be up to 220 km. The ability to climb on sloped roads can be up to 15^o which is tested around the area of the University of Surabaya.

4. Conclusion

The design and fabrication of an electric bicycle is driven by two electric motors, with each electric motor of 350 watts 24V 14.6 Ah. E-bike used a large battery capacity of 24 V 80 Ah which has enough power to carry a total mass of 117.4 Kgf. The maximum speed capability is 30 km/hour on flat road conditions, and the maximum 15^o slope is capable of 10 km/hour with a power of less than 500 watts.

The maximum mileage depends on the speed at which it is used, that based on the calculation of 15 km/hour the bicycle can travel along 263 km. Meanwhile, based on the performance test and confirmation test, with an average speed of 15 to 16 km/hour, you can reach 220 km.

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