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Experimental Investigation of an Electric Bicycle Performance with Capacity of 350 Watt on Consumption of Lithium Battery 36 V 21 AH

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***Abstract*— Electric bicycles, also known as e-bikes, are future bicycles with an electric motor as a locomotive. Electric bicycles using rechargeable batteries can go from 25 to 32 km/h, while more powerful varieties can go more than 45 km/h (28 mph). The research method begins with making an electric bicycle with a 350-watt BLDC motor powered by a 36 V 21 Ah battery, which theoretically will get up to 2 hours of battery use at maximum speed. The test was carried out in terms of travel speed fuel consumption on flat or uphill road conditions. After all the tests have been completed, data on the results of the performance of the electric bicycle can be obtained, and then a graph of the performance characteristics of the electric bicycle can be made. After conducting data analysis based on the graph of the performance characteristics of this electric bicycle, it is concluded that the use of the smallest gear is effective when the electric bicycle is starting, but the low speed and the largest gear are used when the motorbike is running to get a high speed of 32 km. The success of this research will impact Reducing dependency on fossil fuel vehicles.**

***Keywords*— Electric bicycles; speed; energy consumption.**

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I. INTRODUCTION

Environmental pollution has become a concern for many countries because of fossil fuel transportation modes [1]. Examples of fossil fuels, specifically gasoline and diesel, used in internal combustion engines produce toxic gas emissions such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO), and particulates [2]. Furthermore, fossil fuels cause complex problems facing the world: fluctuations in fossil fuel prices, exhaustion, energy security, and global warming. This issue has encouraged researchers to creatively innovate to find alternative fuels and vehicles [3]. Another important issue is energy security [4], Carbon emissions peak in 2030 [5].

One of the innovations to overcome various problems in the transportation sector is an electric bicycle equipped with a rechargeable battery for the electric motor as a movement aid and pedals like bicycles in general [6]. Electric motors helped to reduce cycling fatigue, making these bikes popular with many people, including people with limited physical abilities and the elderly. Breakthrough electric bicycles had advantages such as low maintenance costs, easy access on narrow roads in the middle of residential areas without disturbing noise, and affordable buying prices. The ability to reduce exhaust emissions has made electric bicycles known as green vehicles and have become an alternative transportation choice [7]. Classified two types, a pure electric bicycle and hybride bicycle [8].

Efforts to save fossil fuels and reduce motor vehicle exhaust emissions by riding an electric bicycle as a substitute for transportation in the city in Switzerland have been carried out and stated in the journal by Bucher at et al. [9], assessment of electric bicycles in China regarding the usage cycle of electric bicycles [10], the development of electric bicycles in Poland [11]. Energy savings analysis in a mathematical model building equipped with population data, citizen mobility, distribution of electric bicycles, and weather in Switzerland has been evaluated to approximate the simulation of using electric bicycles in everyday life. Predicted achievement by cultivating riding an electric bicycle in Switzerland will cut exhaust emissions from motor vehicles by 10% and increase the percentage to 17% by expanding to all regions of

Switzerland. Electric bicycles in the island nation in the southwest Pacific Ocean, New Zealand, have been shown to improve environmental quality and have become an effective strategy for reducing exhaust emissions. Investigative data by Elliot et al. [12] have shown exhaust emissions of 26% from motor vehicles and decreased significantly by replacing electric bicycles; therefore, the impact of environmental quality has shown a better indicator than other modes of transport. The government, businesspeople and researchers have focused on increasing driving comfort and effective energy management to maintain the surrounding air quality.

Based on a survey conducted by Nematchoua et al. [13] on the academic community at the University of Liege, Belgium, with nearly 1500 respondents, as many as 70% of people have decided to travel by riding an electric bicycle with a somewhat tiring distance. Respondents reasoned that the road topography going up and down was tough to pass using an ordinary bicycle. Interest in cycling has inspired Bigazzi et al. [14] to study the replacement of motorized transportation with electric bicycles and its market potential. They have built 38 switching patterns of 38 modes of electric bicycle transportation in 24 types of analysis published worldwide. Their report revealed that 33% of people prefer electric bicycle modes, compared to 27% of regular bicycles.

Meanwhile, transportation options by car and walking account for 24% and 10%, respectively. The data illustrates that the popularity of electric bicycles beats other modes of transportation. A survey in North America and Europe conducted by Stilo et al. [15] revealed that about 500 respondents consisting of 70% maximum of 30 years and 17% female respondents, to explore people's preferences for future bicycle transportation. The critical point of the survey results revealed that electric bicycles have comfortable and safe features for riders and local residents on all types of bicycles, including climbing and going downhill.

Electric bicycles have been projected to displace small motorcycles and mopeds with gasoline in China and Germany [16]. Many researchers have focused on the utility of electric bicycles and incredibly efficient battery recharging to shorten the time and increase the battery capacity to extend the duration of use [17]. Moreover, many researchers are also interested in the dynamics of electric bicycles and energy source methods for performance optimization [18]. There is also research on an electric bicycle controller modified to be integrated with the ESP32 to drive an electric bicycle using a 36 V BLDC type motor [19]. Linear control as a unique method of wireless battery charging was carried out by Peter et al. [20] for an electric bicycle with a capacity of 250 W. They have successfully applied linearization conditions; accordingly, recharging the battery could reach a percentage of 93% in a closed loop system with a coupling separation of about 200 mm. The amount of electrical energy consumption associated with bicycle dynamics has been studied in depth by Hung et al. [21] by experimenting with and comparing component structures through computer simulations.

The summary of several previous studies has shown the development of electric bicycles from various points of view, such as environmental impact investigations, prediction of market demand, and applications in the broader community at present and in the future. Although research on electric bicycles has been widely carried out by researchers from various universities around the world, research on electric bicycles in the performance sector and management of electric energy consumption still feels inadequate for the case faced by each researcher. In addition, the stability of the battery charge and the gradual increase in speed while riding an electric bicycle with the road track parameters and the bicycle circuit's structure are challenging research angles. The dynamic structure of electric bicycles has varied developments in each country and its peculiarities that have motivated researchers to conduct this research. The gap in electric bicycle research has prompted experimental investigations of riding electric bicycles with various measurable parameters analyzed to obtain the optimal performance range. So, it is hoped that this research will produce characteristics of electric bicycles with gear ratios.

II. MATERIALS AND METHOD

Electric bicycle materials are obtained locally, and no components are imported from abroad. The assembly of components into an electric bicycle was carried out at the Mechanical Engineering Workshop in Politeknik Negeri Semarang.

A. Materials: Electric Bicycle for Experiment

The experimental support component of an electric bicycle is shown in Figure 1, The design of electric bicycles prioritizes safety [22], and using BLDC with previous research results with good results [23]. Transmission used for electric bicycles of the sprocket bearing and wheel bearing efficiencies 99%, [24]. which consists of a lithium-ion battery placed in the center of the bicycle and a DC motor as a driving force mounted on the rear axle. As an object of research, an electric bicycle was also installed with sensor equipment to capture mechanical and electrical parameters and a Central Processing Unit (CPU) to process signal data.

Fig. 1 Electric bicycle setup as an experimental system

TABLE I
ELECTRIC BICYCLE SPECIFICATION

Measurable factor	rank	Unit
Electric bicycle mass	21	Kg
Wheel radius	0.33	m
Crank length	0.17	M
Motor power	250	W

Measurable factor	rank	Unit
Number of speeds	7	
Rated capacity	9.3	Ah
Battery nominal voltage	36	V
Battery type	Li-ion	

B. *Mathematical Model of Electric Bicycle*

A mathematical model of an electric bicycle with dynamic and kinetic input parameters is built while traveling uphill, as depicted in Figure 1. The dynamics of motion of an electric bicycle fulfills Newton's second law, which can be written as follows [25]:

$$F_p - F_s - F_w - F_r = M\frac{d^2x}{dt^2} \tag{1}$$

Equation 1 consists of the thrust force with the notation F_p minus the slope resistance force with the notation F_s, the overturning resistance force with F_r as the notation, and the wind resistance force with the notation F_w. Meanwhile, on the right side, the total mass is denoted by M (mass of rider, M_r and mass of electric bicycle, M_b), the period is denoted by t, and the distance is denoted by x. F_s as the slope resistance force can be calculated by:

$$F_s = 9.81MG \tag{2}$$

here, G is the notation of slope grade (%) [26]. F_w as wind resistance can be calculated by:

$$F_w = \frac{1}{2}C_d DA\left(v_w + v_g\right)^2 \tag{3}$$

The notation Cd was the dragging coefficient; the notation D was the air density, kg/m; the notation A was the frontal area, m^2; the notation v_w was the wind speed, m/s; and the notation v_g was the speed of motion, m/s [27]. F_r as the rolling resistance force can be calculated by:

$$F_r = 9.81MC_r \cos\alpha \tag{4}$$

Notation C_r was the coefficient of rolling resistance [28], α was the angle of inclination (°). The propulsion force, F_p can be calculated by:

$$F_p R_w = T_p = T_r + T_m \tag{5}$$

The notation T_p was the propulsion torque (N.m), which is the total driver torque, T_r, and motor torque, T_m occurred on pedaling [29]. The notation of R_w was a wheel radius. From the illustration presented in Figure 1, the total driving torque, T_r was expressed in the following equation:

$$T_r = F_{ch}R_{rg} \tag{6}$$

Equation 6 consists of F_{ch} as the chain force and R_{rg} as the rear gear radius. Based on the force model on the electric bicycle for the analysis depicted in Figure 1, F_{ch} was calculated as follows:

$$F_{ch} = \frac{1}{R_{fg}}L_c F_h \cos\theta_{fg} = \frac{1}{\gamma R_{rg}}L_c F_h \cos\theta_{fg} \tag{7}$$

Equation 7 consists of the notation R_{fg} as the front gear radius, L_c as the crank length, F_h as the human force, R_{rg} as the rear gear radius, θ_{fg} as the front gear angle, and γ as the ratio of the transmission sprocket. Equations 6 and 7 are combined to obtain the driving torque with the following equation:

$$T_r = \frac{R_{rg}}{R_{fg}}L_c F_h \cos\theta_{fg} = \frac{1}{\gamma}L_c F_h \cos\theta_{fg} \tag{8}$$

A DC electric motor has been installed in the rear axle of the electric bicycle. When an electric bike goes through an uphill terrain, the rider can turn on the electric motor so that there is no need to spend more energy on pedaling the bike. The following equations 9 and 10 model the performance dynamics of a DC electric motor [30]:

$$L_a\frac{di_a}{dt} + i_a(t)Ra + K_b\omega_m = U_a \tag{9}$$

$$J\frac{d\omega_m}{dt} + B_1\omega_m + T_m = K_b i_a(t) \tag{10}$$

The components of equations 9 and 10 consist of i_a as the armature current, R_a as the armature resistance, U_a as the voltage from the DC motor terminal, L_a as the armature inductance, K_b as a constant of back EMF, J is the inertial torque, B_1 as the coefficient of viscous friction, T_m as the torque motor on the rear axle, and ω_m as the motor speed. The propulsion force equation is obtained from the derivation of several equations, such as 5, 8, 9, and 10, resulting in the following equation:

$$F_p = \frac{T_r + T_m}{R_w} = \frac{1}{\gamma R_w}L_c F_h \cos\theta_{fg} + \frac{1}{R_w}[\frac{K_b}{R_a}U_a - \frac{K_b L_a}{R_a}\frac{di_a}{dt} - J\frac{d\omega_m}{dt} - \left(B_1 + \frac{K_b^2}{R_a}\right)\omega_m] \tag{11}$$

C. *Experimental Setting*

The experimental support component of an electric bicycle is shown in Figure 2, which consists of a lithium-ion battery placed in the center of the bicycle and a DC motor as a driving force mounted on the rear axle. As an object of research, an electric bicycle was also installed with sensor equipment to capture mechanical and electrical parameters and a Central Processing Unit (CPU) to process signal data. It can be seen in Table.1.

III. Results and Discussion

Research activities were carried out at Politeknik Negeri Semarang and used the Energy Conversion Laboratory Mechanical Engineering Department facilities from July to October 2022.

The research results with the steps described above, the experiment was carried out by running the electric bicycle continuously without removing the throttle, and the second trial was releasing the throttle at maximum speed. Research results in the form of speed data, travel time, and power consumption are shown in Table 2.

TABLE II
POWER CONSUMPTION, SPEED AND TIME TAKE ELECTRIC BICYCLE

Steering	Rear gear	Km/h	Time(s)	Wh	Km
Take off the maximum speed throttle	1	19	200	16	1,3
	2	20	200	14	1,2
	3	23	195	14	1,4
	4	26	190	15	1,6
	5	27	180	15	1,7
	6	32	170	16	1,9

Steering	Rear gear	Km/h	Time(s)	Wh	Km
Continue	1	17	300	15	2,9
	2	18	300	16	2,1
	3	19	300	15	2,3
	4	23	300	15	2,5
	5	28	300	16	2,6
	6	32	300	15	2,2

The use of smaller gears will consume more power than lower speed. Using the most extensive gear produces high speed with low energy consumption. The second experiment, by releasing the throttle at maximum speed, produces energy consumption that is more efficient than continuing experiments on the throttle at maximum speed. To find the power consumption per mileage, it can be formulated as follows:

$$\text{Power consumption per km} = \frac{\text{Power consumption(wh)}}{\text{mileage(km)}} \quad (12)$$

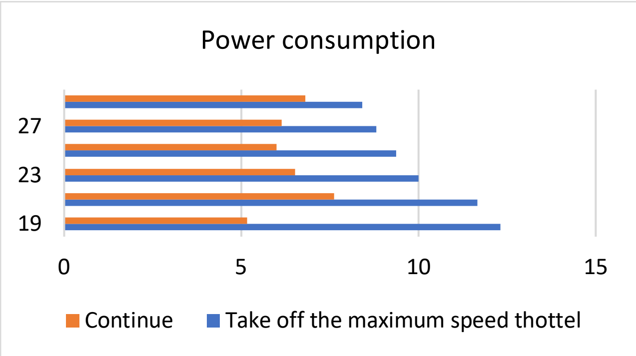

Fig. 2 Take off the maximum speed throttle vs Continuous trial of throttle with maximum speed

Figure 2 shows a comparison graph of the steering pattern which produces an average speed value with the power consumed from electric bicycles obtained from the formula above as well as the results of the average speed and power consumption with different driving patterns, as shown in Figure 3.

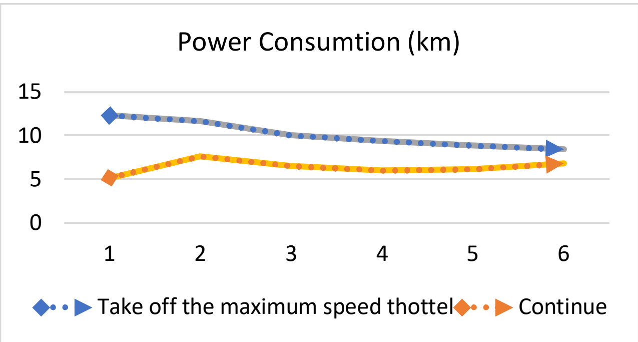

Fig. 3 Power consumption (km)

IV. Conclusion

The performance characteristics of this electric bicycle concluded that using the smallest gear is effective when the electric bicycle is starting, but the low speed and the largest gear are used when the motor is running to get a high speed of 32 km.

Nomenclature

F_p	thrust force	
F_s	slope resistance force	
F_r	overturning resistance force	
F_w	wind resistance force	
M	total mass	
M_r	mass of rider	
M_b	mass of electric bicycle	
T	time period	
x	distance	
G	slope grade	%
Cd	drag coefficient	
D	air density	kg/m
A	frontal area	m^2
v_w	wind speed	m/s
v_g	speed of motion	m/s
C_r	coefficient of rolling resistance	
T_p	propulsion torque	N.m
R_w	radius of wheel	m
T_r	rider torque	
T_m	motor torque	
F_{ch}	chain force	
R_{rg}	rear gear radius	
R_{fg}	front gear radius	
L_c	crank length	
F_h	human force	
R_{rg}	rear gear radius	
i_a	armature current	amp
R_a	armature resistance	ohm
U_a	voltage	Volt
L_a	armature inductance	
K_b	constant of back EMF.	
J	inertial torque	
B_1	coefficient of viscous friction	
T_m	torque motor on the rear axle	

Greek letters

α	angle of inclination	°
γ	ratio of the transmission sprocket	
θ_{fg}	front gear angle	
ω_m	motor speed	

Subscripts

p	thrust
s	slope resistance
r	overturning resistance (in notation F)
w	wind resistance
r	rider (in notation M and T)
b	electric bicycle
w	wind (in the notation F)
g	montion
r	rolling resistance (in notation C)
p	propulsion (in notation T)
w	wheel (in notation R)
m	motor
ch	chain
rg	rear gear
fg	front gear
c	crank length
h	human force
rg	rear gear
a	armature

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