AIP Conference Proceedings

RESEARCH ARTICLE | MAY 03 2023

Power consumption analysis of a brushless DC motor 48V 500W electric bike on an assembled lithium-ion 21700 battery pack

Setiawan Nur Ikhsan; Evvy Kartini

AIP Conference Proceedings 2517, 020013 (2023)
https://doi.org/10.1063/5.0121067

Power Consumption Analysis of a Brushless DC Motor 48V 500W Electric Bike on an Assembled Lithium-ion 21700 Battery Pack

Setiawan Nur Ikhsan [1, a)] and Evvy Kartini [2, b)]

[1]*Department of Electrical Engineering, Faculty of Engineering, University of Diponegoro, Jl. Prof. Sudharto, SH, Kampus UNDIP Tembalang, Semarang 50275, Indonesia.*
[2] *National Battery Research Institute, Edu Center Building Lt 2 Unit 22260, BSD City, Tangerang Selatan 15331, Indonesia*

[a)] *Corresponding author: ikhsan.sn1412@gmail.com*
[b)] *evvy.kartini@n-bri.org*

Abstract. Based on Central Bureau of Statistics data as of 2019, the number of motorcycles recorded is 112,771,136 units or about 84 percent of the total vehicles. Moreover, the pollution caused by motor vehicle exhaust has a very bad impact on air quality in Indonesia, and innovation is needed to overcome this wider impact. Electric bicycles are environmentally friendly transportation because they do not cause exhaust gas and pollution. This study aims to assemble lithium-ion batteries as a power source for electric bicycles and analyze the power consumption of batteries used in electric bicycles with several variations of speed. This study uses an experimental method with the data obtained in the form of battery capacity, battery voltage, the maximum speed of the bicycle, and the distance of the bicycle from full battery to exhaustion. The test was carried out on an electric bicycle with a Brushless DC 48V 500Watt motor drive. The battery used is an assembled lithium-ion type with a total capacity of 48 Volt 15Ah. After three tests, it was found that there was an effect of speed conditions on battery consumption. The initial voltage of the battery is 48V, the lowest voltage is at 41V, and the battery will be discharged at a voltage of 39V. This test concludes that there is an effect of speed conditions on battery consumption, where at high speeds it requires a larger battery voltage than at lower speeds, the higher the speed, the more the battery voltage will drop to move the electric bicycle. **Keywords:** *Lithium-ion Battery 21700, Assembled Electric Bike, Power Consumption.*

INTRODUCTION

Oil-fueled vehicles currently dominate the amount of transportation today, as noted by the Indonesian Central Statistics Agency that the number of motorized vehicles in Indonesia reached more than 133 million units in 2019. Along with this, the adverse impact of using fuel oil is the result of Its combustion produces gas which causes air pollution to increase. In addition, over time, the use of fossil fuels from fossil fuels will eventually run out and cannot be renewed [1].

Electric vehicles are the solution to many of the problems above. Electric vehicles use electrical energy as the main energy source, which is environmentally friendly energy because it does not produce toxic gas emissions, it is also renewable energy.

A bicycle is a non-fueled vehicle that is purchased at an affordable price and requires no paperwork to drive it. However, one of the problems with bicycles is that they cannot be used as long-distance transportation for most users, because they are tired of pedaling a bicycle. Therefore, electric bicycles were created that support bicycles to be driven by pedals and electric energy.

The International Conference on Battery for Renewable Energy and Electric Vehicles (ICB-REV) 2021
AIP Conf. Proc. 2517, 020013-1–020013-8; https://doi.org/10.1063/5.0121067
Published by AIP Publishing. 978-0-7354-4444-7/$30.00

This study aims to assemble lithium-ion batteries as a power source for electric bicycles and analyze the power consumption of batteries used in electric bicycles with several variations of speed. This study uses an experimental method with the data obtained in the form of battery capacity, battery voltage, the maximum speed of the bicycle, and the distance of the bicycle from full battery to exhaustion. The test was carried out on an electric bicycle with a Brushless DC 48V 500Watt motor drive. The battery used is an assembled lithium-ion type with a total capacity of 48 Volt 15Ah.

METHODOLOGY

Materials

Lithium-ion battery is chosen as battery type for the module. The specification of li-ion battery that is use in this research is Lithium-ion Battery NMC21700 with a voltage of 3.6V and a capacity of 5000mAh with dimensions of Ø21.25 × 70.8 mm. Lithium-ion or Li-ion battery has many advantages over other types of batteries like NiMH battery and SLA battery. The comparison of battery types is shown in Table 1, according to epectec.com.

Table 1. The comparison of battery types

Specification	SLA	NiMH	Li-ion
Life Cycle	200-300	300-500	500-1000
Energy Density	30-50	60-120	150-190
Self-Discharge/month	5%	20%	<10%
Fast-Charge Time	8-16h	2-4h	2-4h
Cell Voltage	2V	1.2V	3.6V

There are also several materials that needed beside battery to make a battery pack module; Battery Management System or BMS for balancing the voltage of each cell, avoiding overcharge and over discharge; Brushless DC motor as the main driving force of the bicycle; controller as a bicycle speed controller from gas to motor; throttle gas to open and close the speed.

This research is an experimental research by analyzing the power consumption of an assembled Lithium Ion 21700 battery on an electric bicycle. In the implementation, the data obtained are in the form of battery capacity, battery voltage, maximum speed of the bicycle and the distance traveled by the bicycle from full battery to exhaustion. After that, an analysis of the data that has been obtained is carried out to answer the research objectives that have been made [2].

Design Model

For this research, we design a battery module with a voltage of 48V and a capacity of 15Ah so it has a power of 720Wh. Those specification are chosen because have a big capacity so the bike can travel long distance, although have small size so the bike still light. One cell of li-ion battery NMC21700 has a working voltage of ±3.70V and a capacity of ±5Ah. So, to make a battery module with 48v and 15Ah, it takes about 13 cells in series and 3 in parallel. The configuration of battery module is cells directly connected in parallel then assembled in series like shown in Figure 1.

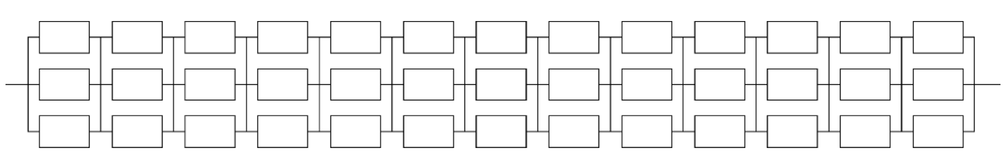

FIGURE 1. Battery module configuration with 13 series and 3 parallel.

This configuration is chosen based on research conducted by Federico Baronti and his friend (2014). They found that battery configurations with modules directly connected in parallel and then assembled in series are more robust against variation of the cell capacity through the battery. The result of that research show that the series connection of parallel modules of cells provides the best connection topology, as it maximizes the capacity of the pack and reduces the statistical dispersion of the values [3].

FIGURE 2. Battery pack module

For safety step, On the left there is a battery pack module that has been coated with fiber glass insulation so that the heat from the battery can be minimized, then the middle one is a battery pack module that has been coated with pvc wrap shrink.

(a) **(b)**

FIGURE 3. (a) Electric Bike (b) Folded Electric Bike

And this is the model of the bicycle; brushless DC motor we installed in the rear wheel; for the controller we put under the bicycle seat; throttle gas on the right side of the bicycle handlebar; and for the battery pack module we put in the middle frame of the bicycle. In this design, we consider this bike to be as portable as its original function, which is that it can be folded. For figure b we can look how an electric bicycle is folded properly and its dimensions are 410 cm long, 520 cm high and 170 cm wide. This design is very portable and can be carried anywhere.

RESULTS AND DISCUSSION

After the model of the battery pack module and the electric bike. The next step is making the battery pack module and testing the battery pack on an electric bike.

1. Measure the internal resistance value of every cells

Before start to put cells in accordance with the configuration, each of cell have to be measured its internal resistance value. Before the battery is measured, we put a number in each cell to make it easier to record the measurement results. We measure 13 batteries; the following are the results of measuring the voltage and internal resistance of each battery as shown in Table 2.

Table 2. Battery module configuration according to internal resistance value.

		Parallel Configuration		
		P1	**P2**	**P3**
Serial Configuration	**S1**	15.265	15.698	15.789
	S2	17.455	17.23	17.08
	S3	17.556	17.525	17.849
	S4	18.27	18.07	18.17
	S5	18.7	18.85	18.33
	S6	20.19	20.19	20.19
	S7	20.19	20.19	20.19
	S8	20.19	20.19	20.19
	S9	20.19	20.19	20.21
	S10	20.26	20.21	20.26
	S11	24.7	24.7	24.7
	S12	24.7	24.7	24.7
	S13	24.7	24.7	24.7
	Total	**262.366**	**262.443**	**262.358**

And measuring the value of internal resistance is a very important aspect when arranging battery cells according to configuration, especially for parallel connection. This is based on the results of research conducted by Radu Gogoana and his friend (2014). They found that 20% difference in cell internal resistance between two cells cycled in parallel can lead to approximately 40% reduction in cycle life when compared to two cells parallel-connected with very similar internal resistance [4].

The battery module is obtained with the appropriate number of battery cells to meet the requirements and capacity requirements. Batteries can be used in parallel to get a higher capacity or batteries in series to make a battery module with a higher voltage. As previously mentioned, to make a battery module with 48V and 15Ah using the NMC21700 Li-ion cell, it takes about 13 in series and 3 in parallel. The cells are arranged so that the total internal resistance values of each parallel configuration are the same or adjacent. The table above shows the configuration of the battery modules according to the internal measurement results with the number of each cell. For the battery pack module that is ready to be installed, we can see in the image below.

FIGURE 4. Battery pack module with 3D print casing

The test was carried out by riding an electric bicycle from a full battery condition until the battery could not move the electric bicycle, the data obtained in the form of battery usage time, bicycle speed, battery temperature, battery voltage, current flowing. The data results will be displayed using a graph so that it can be seen the maximum use of the 21700 lithium ion battery.

Calculation of the power used can be done using the following formula:

$$P = I \text{ X } V \quad (1)$$
$$W = P \text{ X } t \quad (2)$$
$$v = t/S \quad (3)$$

Note:
P = Power (W)
I = Discharging current (A)
V = Voltage (V)
t = Usage time (h)
W = power consumed (W)
v = bicycle speed (km/h)
S = distance traveled (Km)

The measurement of the voltage and current values of the 21700 lithium ion battery is carried out after the assembly process. The battery is assembled according to Table 2. Based on the data obtained, it can be analyzed the results of the power consumption of the assembled 21700 lithium ion battery used

Battery power capacity:
Current (I) : 44.439A
Voltage (V) : 54.12V
Power (P) : 720.06 Watt
Calculates the maximum time the battery can provide electricity
t = 720.06Watt / 500Watt
= 1,440 hours
= 86.400 Minutes
Calculating the maximum power that can be consumed
W = P x t
= 720.06 x 1,440
= 1036.886,4 Watt

2. Testing the battery in electric bike

Furthermore, the test table 1 shows the results of the first test. The test data for electric bicycle battery consumption includes usage time, speed, distance traveled, battery temperature and battery voltage. Battery power is obtained from the process of multiplying the measured voltage and current.

TABLE 3. Result data from first test on battery

No.	Time (minutes)	Average speed (Km/hour)	Distance (Km)	Temperature (Celcius)	Initial Voltage (V)	Current (I)	Battery Power (Watt)	Running Voltage (V)
1	9.12	45.90	26.2	28.8	52.9	3.98	97.47	51.9
2	9.89	44.78	28.6	31.2	52.7	4.76	94.7	52.1
3	10.67	45.79	25.3	30.4	53.9	4.77	95.23	51.6
4	11.86	43.14	29.4	29.6	53.7	4.98	94.69	51.2
5	11.98	43.19	38.3	32.5	52.5	4.86	95.19	50.7
6	11.63	42.73	41.6	30.6	51.9	4.65	97.77	50.3
7	12.98	42.46	44.4	31.5	51.2	4.99	95.93	50.2
8	13.76	42.23	46.4	31.4	50.6	4.54	96.43	50.4
9	12.21	42.12	48.2	32.6	50.1	4.72	97.56	49.5
10	8.43	13.87	12.6	32.8	49.6	4.81	78.87	49.2
11	8.28	14/71	13.2	32.6	49.3	4.89	48.56	48.2
Total	79.54	478.97	48.2				989.1	

The first test used 79,54 minutes to reach a distance of 48,2 km with a battery power of 989,1Watts. At the time of testing the travel time of 138 minutes the battery stopped providing current at a working voltage of 48.2V. When testing the bicycle handle, it is rotated in the full position so as to produce full speed, as a result the motor requires a higher voltage to be able to move the electric bicycle. The study was stopped at number 11 because the battery temporarily stopped providing current to drive the electric bicycle.

TABLE 4. Result data from second test on battery

No.	Time (minutes)	Average speed (Km/hour)	Distance (Km)	Temperature (Celcius)	Initial Voltage (V)	Current (I)	Battery Power (Watt)	Running Voltage (V)
1	10,12	45,90	26.2	28.8	52.9	3.98	97,47	51.9
2	11,89	44,78	28.6	31.2	52.7	4.76	94,7	52.1
3	11,67	45,79	25.3	30.4	53.9	4.77	95,23	51.6
4	11,86	43,14	29.4	29.6	53.7	4.98	94,69	51.2
5	10,98	43,19	38.3	32.5	52.5	4.86	95,19	50.7
6	12,63	42,73	41.6	30.6	51.9	4.65	97,77	50.3
7	12,98	42,46	44.4	31.5	51.2	4.99	95,93	50.2
8	13,76	42,23	46.4	31.4	50.6	4.54	96,43	50.4
9	14,21	42,12	59.2	32.6	50.1	4.72	97,56	49.5
10	6,43	13,87	12.6	32.8	49.6	4.81	78,87	49.2
11	8,28	14,71	13.2	32.6	49.3	4.89	48,56	45.9
Total	84,54	478,97	59.2				1001,4	

This table shows the results of the second test, the usage time of 146.56 minutes reaches a distance of 58.2 Km and the power used is 1056.4 Watt. The mileage in test 2 is further because at minute 126-146 the electric bike is not forced to move on the handle rotation full, so the speed can only last at 5.71 Km/hour, until the 45.9V battery voltage stops providing current to drive the electric bicycle.

TABLE 5. Result data from third test on battery

No.	Time (minutes)	Average speed (Km/hour)	Distance (Km)	Temperature (Celcius)	Initial Voltage (V)	Current (I)	Battery Power (Watt)	Running Voltage (V)
1	11.14	45.90	26.2	28.8	52.9	3.98	97.47	51.9
2	13.69	44.78	28.6	31.2	52.7	4.76	96.7	52.1
3	14.57	45.79	25.3	30.4	53.9	4.77	96.23	51.6
4	15.46	43.14	39.4	29.6	53.7	4.98	96.69	51.2
5	15.98	43.19	48.3	32.5	52.5	4.86	96.19	50.7
6	15.63	42.73	54.6	30.6	51.9	4.65	97.77	50.3
7	17.98	42.46	56.4	31.5	51.2	4.99	98.93	50.2
8	19.76	42.23	60.4	31.4	50.6	4.54	96.43	50.4
9	20.21	42.12	78.7	32.6	50.1	4.72	99.56	49.5
10	9.43	13.87	13.6	32.8	49.6	4.81	78.87	49.2
11	7.28	14.71	11.2	32.6	49.3	4.89	48.56	45.9
Total	86.54	478.97	78.7				1035.8	

This table shows the results of the third test, the usage time of 86.54 minutes reaches a distance of 78.7 Km and the power used is 1035.8Watts. In this test, the electric bicycle from 146-165 minutes moves at a low speed so it only requires a low voltage as a result the distance is longer than in the previous test. At number 13 the battery has stopped providing current for a while, if the bicycle handle is forced to turn full the battery voltage drops very quickly as a result the battery stops providing electric current.

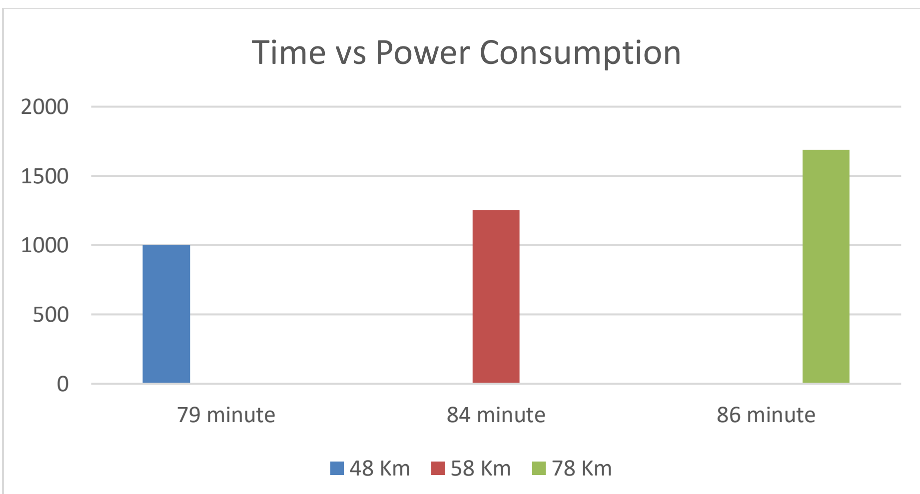

FIGURE 5. The graph between Time vs Power Consumption.

In the graph comparing the distance between power consumption and time, it can be analyzed that the higher the speed, the faster the travel time but requires a larger battery consumption, at lower speed conditions the travel time is longer but the power consumption required is less.

CONCLUSION

In testing the bicycle is driven at its maximum speed, the test is carried out with a rider's tire load of 65Kg, the battery voltage continues to decrease with increasing distance traveled, the distance in the first test is 48.2 km with a battery power of 989.1Watts and the 2nd as far as 58.2 Km and the power used is 1056.4 Watts, the largest mileage occurred in the 3rd test which is 78.7 Km and the power used is 1035.8 Watts. In numbers 1-11 the speed continues to decrease along with the decrease in battery voltage, at 12-13 minutes the bicycle is only able to move at low speed. If the bicycle is forced to move at its highest speed, the battery is unable to move the bicycle and stops supplying electricity. This shows the effect of speed conditions on battery consumption, where at high speeds it requires a larger battery voltage than at lower speeds, the higher the speed, the battery voltage will drop more to move the electric bicycle. The minimum battery charging time is 7 hours 49 minutes and the maximum are 8 hours 13 minutes, the longer the battery will require charging if the battery is used longer.

ACKNOWLEDGMENTS

This work is partially supported by LPDP number 84/E1/PRN/2020through the National Research Priority (PRN) Mandatory on Energy Storage 2020 under the Ministry Research and Technology.

REFERENCES

1. "Badan Pusat Statistik." https://www.bps.go.id/linkTableDinamis/view/id/1133 (accessed Jul. 24, 2021).
2. W. F. Syafra and H. A. K, "Power Consumption Analysis of a BLDC 24V 250W Electric Bike on An Assembled Lithium-ion Battery Pack Analisis Konsumsi Daya Baterai Lithium-ion Rakitan oleh Sepeda Listrik Berpenggerak Motor BLDC 24V 250W," *Motivection*, pp. 1–10, 2020.
3. F. Baronti, R. Di Rienzo, N. Papazafiropulos, R. Roncella, and R. Saletti, "Investigation of series-parallel connections of multi-module batteries for electrified vehicles," *2014 IEEE Int. Electr. Veh. Conf. IEVC 2014*, 2014, doi: 10.1109/IEVC.2014.7056173.
4. R. Gogoana, M. B. Pinson, M. Z. Bazant, and S. E. Sarma, "Internal resistance matching for parallel-connected lithium-ion cells and impacts on battery pack cycle life," *J. Power Sources*, vol. 252, pp. 8–13, 2014, doi: 10.1016/j.jpowsour.2013.11.101.