engineering proceedings

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Proceeding Paper

Analysis of Lithium-Ion Battery Consumption for Three-Wheeled Electric Vehicle with Variations in Weight and Speed †

Alex Taufiqurrohman Zain *, Dwi Djoko Suranto, Cahyaning Nur Karimah, Faruq Avero Azhar and Dicky Adi Tyagita

Program Study of Automotive Engineering, Engineering Department, Politeknik Negeri Jember, Mastrip Street, Jember 68121, Indonesia; dwi_joko@polije.ac.id (D.D.S.); cn.karimah@polije.ac.id (C.N.K.); faruq.avero@polije.ac.id (F.A.A.); dickyadi@polije.ac.id (D.A.T.)

* Correspondence: alextaufiqurrohman@polije.ac.id; Tel.: +62-823-3396-2659

† Presented at the 7th Mechanical Engineering, Science and Technology International Conference, Surakarta, Indonesia, 21–22 December 2023.

Abstract: Electric vehicles have promising prospects for development. Our research method began with the stages of designing and calculating of a three-wheeled electric vehicle prototype. The prototype design was realized through fabrication of frame and body components. Furthermore, testing by providing weight variations was carried out in this research. This paper will determine the performance of the electric vehicle and the battery used. With the lightest weight (45 kg) at a slow speed (12 km/h), the lowest voltage drop was obtained, 6.36 V, while with the heaviest load (105 kg) at a higher speed (17 km/h), the highest decrease in voltage value was obtained, 8.96 V. Meanwhile, the measured electric current was still fluctuating. It was found that when deceleration occurs, the flowing current decreases, whereas when acceleration occurs, there is an increase in the value of the electric current.

Keywords: acceleration; three-wheeled electric vehicle; weight variations

Citation: Zain, A.T.; Suranto, D.D.; Karimah, C.N.; Azhar, F.A.; Tyagita, D.A. Analysis of Lithium-Ion Battery Consumption for Three-Wheeled Electric Vehicle with Variations in Weight and Speed. *Eng. Proc.* **2024**, *63*, 13. https://doi.org/10.3390/engproc2024063013

Academic Editors: Waluyo Adi Siswanto, Sarjito, Supriyono, Agus Dwi Anggono, Tri Widodo Besar Riyadi and Taurista Perdana Syawitri

Published: 28 February 2024

1. Introduction

Recently, the Indonesian Government provided real support regarding the development of electric vehicles, especially the BEV type [1–3]. This is proven by several strategic policies issued, including the issuance of Presidential Regulation of Indonesia Number 55 of 2019 concerning the acceleration of the Battery-Based Electric Motor Vehicle Program for road transportation, the National Research Master Plan 2017–2045 of Indonesia Minister of Research, Technology and Higher Education regarding the use of electric vehicles as public transportation, and the development of supporting infrastructure in the battery and electric vehicle industry and through public electric vehicle charging stations [4–6].

Design is one of the initial stages in developing a three-wheeled electric vehicle. In this research, drafting designs have been developed that are related to three-wheeled electric vehicles which will later be manufactured. The drafting design that has been developed is for a commodity transport vehicle with a pick-up bed and a roof that can be dismantled. This design selection was adjusted by considering the availability of existing components and resources, as well as looking at wider market share for a prototype for three-wheeled electric vehicles. To optimize their performance, electric vehicles require a control system. The control system that will be developed is related to the electric motor control system and battery voltage monitoring.

A battery is an electric cell in which a reversible electrochemical process takes place with high efficiency [7,8]. Lithium-ion batteries are the right choice to use in this research because they have the advantages of high energy density, high power density, low self-discharge, fast charging, no memory effect, and long cycle life [9–11]. However, lithium ion-based batteries only produce a voltage of 3.7 V per cell. Therefore, if you want to use them as an energy source in an electric vehicle, you need several lithium-ion battery cells connected in series and parallel to form a battery pack [12,13].

2. Method

Research on three-wheeled electric vehicles begins with determining and designing an electric vehicle. The design was carried out using Solid Work software (https://www.solidworks.com/product/solidworks-3d-cad). The design that was obtained was further designed and assembled in PT. Manufacture Dynamic Indonesia (MDI) workshop. After the body frame and electric bicycle components were assembled, the electric vehicle control system was designed. This control system will later determine the rotational speed of the actuator and electric motor based on the driver pulling the steering wheel. This control system will also determine electrical energy needed according to the vehicle's weight. The battery voltage monitoring system was designed and assembled during this research. Furthermore, the performance of electric vehicles and batteries under various weight was carried out at the Automotive Engineering Laboratory and Politeknik Negeri Jember Campus Area. It is hoped that several series of experiments in this research will be able to produce three-wheeled electric vehicles that comply with safety standards and provide driving comfort.

This research can be briefly summarized in the following stages.

2.1. Design Drafting

There are several differences in the design of this vehicle (Figure 1) compared to conventional ones. In this vehicle, there is no longer a fuel tank, so this will affect the design of the driver's seat. In conventional vehicles, the seats are designed to face straight forward. In this vehicle, it is shaped sideways. Furthermore, for the rear bed, this vehicle has two racks and a roof that can be dismantled. This is intended for multifunctional use.

Figure 1. Design of three-wheeled electric vehicle.

2.2. Component Fabrication

This process was carried out at the workshop of our partner, PT. Manufacture Dynamic Indonesia (see Figure 2). This partner already has equipment that is adequate for the manufacturing process, including CNC laser cutting machines for cutting the chassis, rear bed, body parts, and other metal materials; a milling machine used to make the front brake caliper bracket; a lathe used to make connections for the rear brake axle, leaf spring lock, rear lock axle, and front axle; and bending machines used to form frames, rear bed, and steering handlebars. Welding machines were used to connect components to be assembled.

(**a**) (**b**)

Figure 2. Component fabrication including (**a**) milling process and (**b**) lathe process.

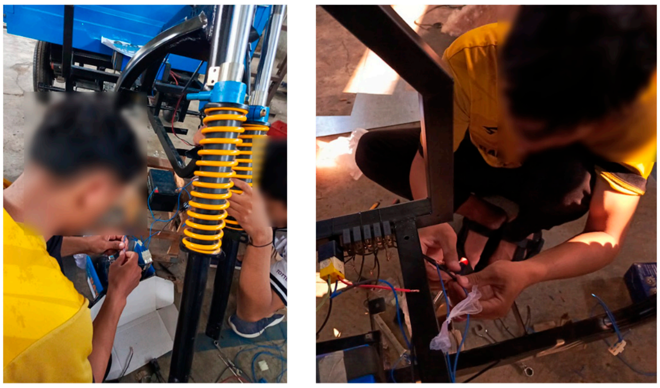
2.3. Mechanical Component Assembly

After the components were made, the next stage was assembly. When assembling mechanical components, one of the things that needs to be considered is the fitting and welding process. This process is shown in Figure 3. The component fitting process is easier if one has previously carried out the drafting process. The shielded metal arc welding (SMAW) method was used for welding process. The SMAW method was chosen because it is a welding technique that has high flexibility and efficiency [14,15]. SMAW is a process of joining two or more pieces of metal into a permanent connection using an electric heat source and additional/filling materials in the form of wrapped electrodes [16,17].

Figure 3. Mechanical components assembly after welding process.

2.4. Electrical Component Assembly

In general, there are two activities in this process: (1) connecting the electric motor and control system to the main power source (Li-ion battery). The electric motor used is a brushless direct current (BLDC)-type motor with a capacity of 3 kW. BLDC motor is a type of synchronous motor. In a brushless direct current motor, the magnetic fields produced by the rotor and stator at the same frequency. The selection of this type of motor was based on its high power density, increased performance, cheaper maintenance costs, efficient control, and uncomplicated equipment settings [18]. Meanwhile, the 3 kW capacity was chosen because we planned to use the vehicle being made as a multifunctional transport vehicle, so it needed an adequately large electric motor capacity. Meanwhile, the type of battery used as a main power source was lithium-ion 84 volt. This type of battery was chosen because lithium-ion batteries are currently the most suitable technology for electric vehicles. This is because they can provide high energy and power per unit of battery mass; therefore, they are lighter and smaller than other rechargeable batteries. Other advantages of lithium-ion batteries compared to lead–acid and nickel–metal hydride batteries include higher energy efficiency, no memory effects, and relatively long cycle life [9,19]. (2) Connecting the electrical accessories such as headlamps, stop lamps, turn signals, speedometer, and horn to a secondary power source, namely, a Pb batteries. Pb batteries are used so that the electrical load can be divided. This will lengthen the life of a Li-ion battery. These processes can be seen in Figure 4.



(**a**) (**b**)

Figure 4. Electrical component assembly to (**a**) Pb battery and (**b**) Li-ion battery.

2.5. Battery Consumption Testing

The next step was the testing process for three-wheeled electric vehicles. We carried out tests to measure the capacity of the lithium-ion battery used by vehicle under variations in weight and speed. This is necessary to determine whether the battery used was sufficient to supply energy to the electric motor and to determine the characteristics of the battery at various speeds.

3. Results and Discussion

For track conditions, electric vehicles were tested on a relatively flat surface for 1200 m. For each driver's weight, the speed used was 12 km/h and 17 km/h. The choice of speed was based on the existing track. At speeds above 17 km/h, it was feared that road conditions would disturb the vehicle and that speed would decrease and fluctuate. Calculating the speed of an electric motorbike was carried out using the wheel's center connection equipped with a monitoring system from the smartphone-based Strava application. This application can display map route data complete with global positioning system (GPS), average speed, and distance traveled. The lower voltage of the battery is limited to 71 volts. All of the results of this study are shown in Table 1.

At a speed of 12 km/h, it takes 5 min, on average, to cover 1200 m; it takes 4 min to cover the same distance at a speed of 17 km/h. To measure battery consumption during testing, a watt meter was needed. Later, the difference between the battery voltage before being tested and the battery voltage after being tested was calculated. Figure 5 shows the voltage for various weights at 12 km/h; Figure 6 shows the same at 17 km/h.

The test results at speeds of 12 km/h and 17 km/h shows that an increase in the weight of the vehicle produces a decrease in voltage value. At a speed of 12 km/h, when a weight of 45 kg, 70 kg, and 105 kg was applied, the decrease in voltage values was 6.36 V, 6.5 V, and 8.06 V, respectively. Meanwhile, at a speed of 17 km/h, the decrease was 6.38 V, 6.73 V, and 8.96 V, respectively.

Table 1. Power consumption for various weights and speeds.

Weight (kg)	Time (s)	Speed 12 km/h			Speed 17 km/h		
		Voltage (V)	Current (A)	Power (Watts)	Voltage (V)	Current (A)	Power (Watts)
45 kg	1	81.13	3.92	299.6	81.1	11.81	153.1
	60	77.72	10.06	112.8	78.46	19.64	153.8
	120	77.59	5.08	844.6	76.17	14.55	103.3
	180	76.82	6.01	442.4	75.52	19.44	130.7
	240	75.22	9.28	669.6	74.05	15.57	105
	300	74.77	2.2	162.9			
70 kg	1	80.7	5.11	489.2	80.23	16.17	550.6
	60	76.16	10.37	804.6	78.06	20.25	145.2
	120	75.38	7.160	556.4	76.66	15.74	113.7
	180	74.74	9.370	779.8	74.52	19.64	138.4
	240	74.49	11.43	871.1	73.50	15.65	111.4
	300	74.20	10.05	936.8			
105 kg	1	80.03	10.01	306.0	80.12	19.78	690.1
	60	74.09	15.10	112.8	75.27	20.71	155.6
	120	73.62	9.740	734.2	74.72	16.24	122.2
	180	72.32	11.09	406.6	74.21	21.87	161.4
	240	72.16	14.31	105.8	71.16	17.93	132.7
	300	71.97	12.53	746.8			

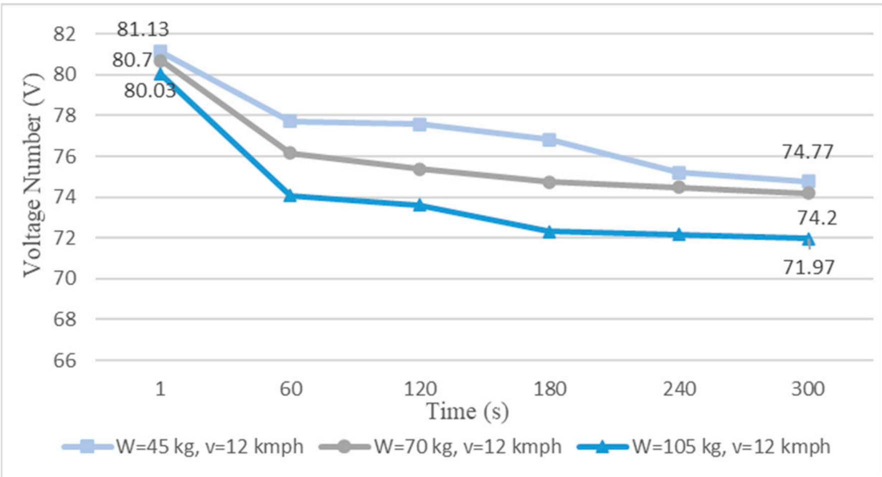


Figure 5. Voltage for various weights at 12 km/h.

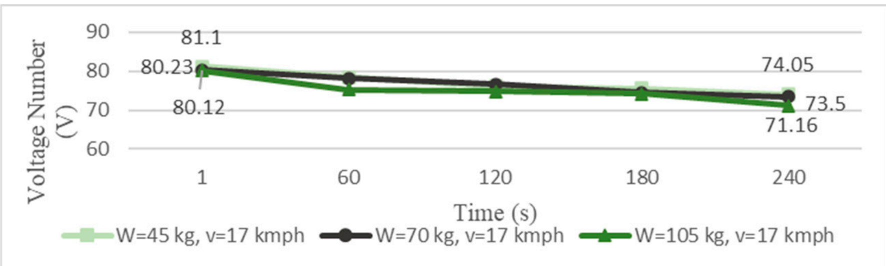


Figure 6. Voltage for various weights at 17 km/h.

These results were obtained because increased weight caused the electric motor to require more energy to move the vehicle. With increasing electrical energy consumption, there will be a greater decrease in battery voltage [20,21].

Regarding the electric current value under variations in weight, both for speeds of 12 km/h and 17 km/h, the values obtained fluctuated. During the test, the vehicle speed changed due to the track conditions. In addition, the test results show that when the vehicle decelerated, the electric current value decreased. This happened when there was a turn and the test ended. Conversely, when the vehicle accelerated, the electric current value increased. Figure 7 shows the current number for various weights at 12 km/h; Figure 8 shows the same at 17 km/h.

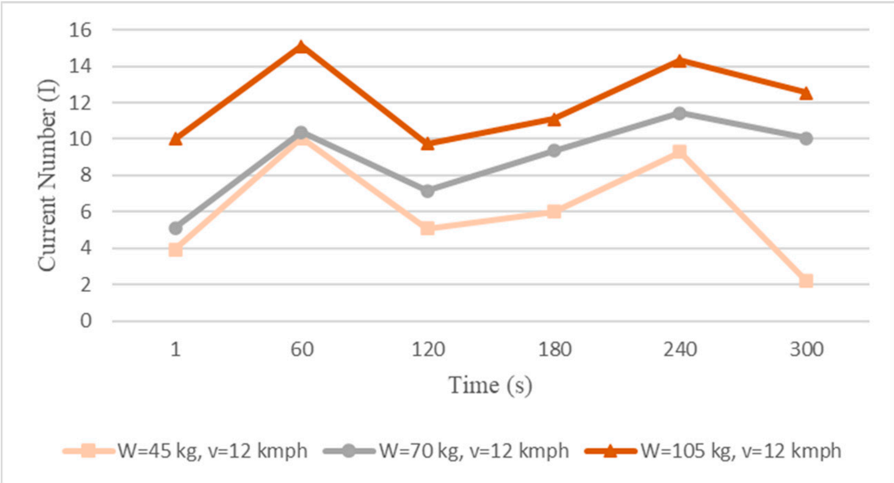


Figure 7. Current number for various weights at 12 km/h.

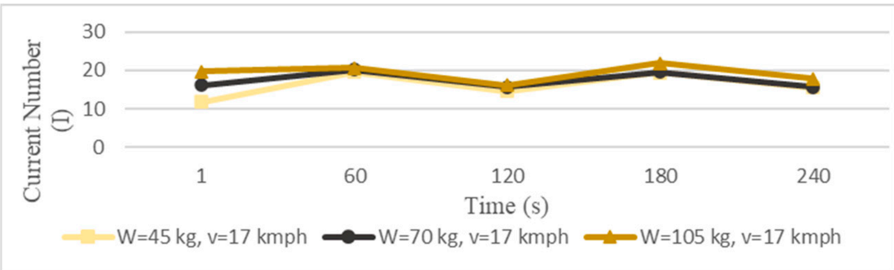


Figure 8. The current number for various weights at 17 km/h.

This occurs after passing a turn as well as when starting the test. Vehicle acceleration requires more energy; therefore, the current required to generate the electric motor increases. Apart from that, vehicle weight also affects the electric current required by the electric motor. The greater of vehicle's weight, will affect on greater electric current that required to power the electric motor [22].

4. Conclusions

The result data show that the application of a greater weight and speed causes a greater decrease in battery voltage values. Regarding electric current, a greater weight and speed meant that a greater current value was required to drive the electric motor. This is because electric motors require more energy to operate. The largest decrease in voltage value was 8.96 V, and the highest value of current flowing to the electric motor was 21.87 A, both of which occurred when the electric vehicle was traveling at a speed of 17 km/h with a weight of 105 kg.

Author Contributions: Conceptualization, A.T.Z. and D.D.S.; methodology, C.N.K.; software, F.A.A.; validation, D.A.T.; formal analysis, A.T.Z.; investigation, A.T.Z.; resources, C.N.K.; data curation, D.D.S.; writing—original draft preparation, F.A.A.; writing—review and editing, A.T.Z.; visualization, D.A.T.; supervision, D.D.S.; project administration, C.N.K.; funding acquisition, D.D.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Direktorat Jendaral Pendidikan Vokasi, Politeknik Negeri Jember, and PT. Manufactur Dynamic Indonesia with grant number IDR 711683500. And The APC was funded by Direktorat Jendaral Pendidikan Vokasi.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The date is available at https://drive.google.com/drive/folders/1JPNllqBO1z_33b2fgBI5QrCKjnnO2i9W?usp=sharing (accessed on 10 December 2023).

Acknowledgments: For the completion of this project, we thank the Direktorat Jendral Pendidikan Vokasi, Politeknik Negeri Jember, and PT. Manufactur Dynamic.

Conflicts of Interest: The authors declare no conflicts of interest.

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