Regenerative Braking on Electric Scooters with DC Magnet Permanent Motors

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Abstract. There are still very few alternatives to medium-distance vehicles that are able to connect places that is unreachable neither by public transportation facilities nor on foot. An environmentally friendly vehicle is needed and able to synergize with existing public transportation, namely electric scooters. Electric scooters that use a permanent MAGNET DC motor as an actuator, still have several obstacles, such as the duration of braking that is too long and the energy that is wasted into heat when braking that leads to wasteful battery consumption, additionally the heat can also damage scooter components. To overcome these obstacles, a regenerative braking system was designed. The results of simulation and testing directly prove that the regenerative braking system designed successfully works according to the design specifications and is able to increase the mileage of the electric scooter.

Keywords: Electric scooter, Permanent magnet DC motor, Regenerative braking, Mileage increase, Braking duration

1 Introduction

Jakarta, the capital of Indonesia, which has a population of 10.56 million people in 2020 [1], makes the air quality in Jakarta worse every year, even not infrequently unhealthy, especially for sensitive people [2]. Based on a source apportionment study conducted by Vital Strategies, in the dry and rainy seasons in 2019, exhaust fumes from motor vehicles are the highest contributor to pollutants in Jakarta's air [3]. One of the steps taken by the government to overcome this problem is to provide public transportation that connects parts of Jakarta and also connects Jakarta with surrounding cities. Unfortunately, this has an impact on the difficulty of reaching certain places whose positions and distances do not allow for public transportation infrastructure to be traversed or built on foot. In cases like this, it is important to have a small vehicle that can be carried in public transportation and does not produce pollution, such as an electric scooter. Gojek Group's Head of Transport, Raditya Wibowo, stated that the popular destinations for online motorcycle taxis are precisely electric train stations and intercity train

ICO-SEID 2022, November 23-24, Jakarta, Indonesia

DOI 10.4108/eai.23-11-2022.2341597

stations, not malls or restaurants, and travel with Gojek to and from public transportation facilities continues to grow by 46% every year [4]. This proves that people need vehicles that can connect between public transportation facilities that have now entered into their primary needs [5].

As a vehicle, an electric scooter must have the ability to work on two conditions, namely motoring or running conditions and braking or braking conditions. In the previous study, the focus of the discussion only included motoring conditions, even though braking conditions were equally important, especially in terms of driving safety. Based on article 62 pp no. 43 of 1993 concerning Traffic Procedures, the safe driving distance is 3 seconds between vehicles. Because the average human takes 1 to 1.5 seconds, the maximum duration required for a braking system to stop the speed of the vehicle is 1.5 to 2 seconds [7, 8]. There are 3 types of braking, namely plugging, dynamic, and regenerative. Regenerative braking has an advantage over two other methods, which can regenerate energy by converting mechanical energy into electrical energy during the braking process [9]. Taking into account the needs of electric scooters to be able to reach their destination before the power stored in the battery is exhausted and the target of implementing electric scooters whose use is on small roads so that braking will often be carried out, this regenerative braking system is considered suitable for application so that it can increase the mileage of electric scooters.

2 Literature Review

2.1 Regenerative Braking

Regenerative braking is a braking method similar to the dynamic braking method, which is to raise and lower the voltage of the electricity supply to the motor until the motor stops rotating. The difference between the two is that the process of utilizing the residual rotation in systems that use the dynamic braking method will be allowed to dissipate into heat, while in systems that implement the regenerative braking method, the remaining wheel rotation will be converted back into electricity which can be stored on the storage device to increase the mileage by about 5% [11].

The amount of returnable current is calculated using the following equation

$$V_{dc} = \frac{E}{(1-d)} \tag{1}$$

$$I_{reg} = \frac{V_{dc} - V_{baterai}}{R} \tag{2}$$

Information:

V_{dc} = Regenerative braking *output* voltage
I_{reg} = Regenerative current
E = Voltage BEMF
d = *Duty cycle* regenerative braking
$V_{battery}$ = Voltage on battery
R = Overall system bottlenecks

2.1 DC Machine

A DC machine is a machine where if given a voltage it will become a motor and when given kinetic energy it will become a generator. The DC generator itself is an electrical machine that can convert mechanical energy into electrical energy and produce direct current [9]. With the same construction between a DC generator and a DC motor, both can operate the other way around and will have identical properties [10]. A DC machine can be described through its equivalent circuit contained in **Figure 1**.

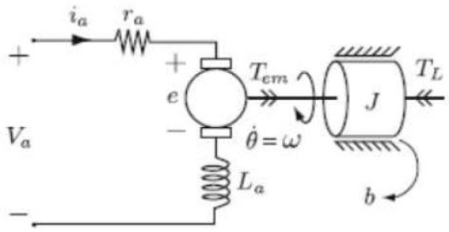

Fig 1. DC Engine Equivalent Model

The electrical system that occurs in the equivalent circuit of a DC engine can be expressed in its Kirchoff equation, namely:

$$V_a - i_a R_a - L_a \frac{d}{dt} i_a - k_e \omega = 0 \quad (1)$$

With its BEF voltage valued it is listed as $k_e\omega$.

3 Discussion

3.1 Braking Performance Testing And Battery Consumption

In this test, braking performance and battery consumption were tested by observing the response of speed and armature current and the current that was successfully returned through the circuit of the regenerative braking system in four different systems, namely without a controller and regenerative braking (system 1), using only a controller (system 2), using only regenerative braking (system 3), and using regenerative controllers and braking (system 4). This test was carried out for 10 minutes based on the minimum duration of use of an electric scooter at a speed of 500 RPM. Every 115th second is braking for 5 seconds. Thus obtained comparative data recorded in Table 1.

Table 1. Comparison of Braking Performance and Battery Consumption Between Systems

System	Braking Duration(s)	Speed Response	Charging Capacity (Ah)	Total battery consumption (Ah)	Maximum Mileage (km)
1	1	Lots of noise	0	0.5043	82.262
2	>5	Little noise	0	0.522	79.473
3	1	Lots of noise	0.00153034	0.49046966	84.593
4	1	Little noise	0.00036778	0.50163222	82.705

Based on Table 1, system 4 can be selected as the system to be applied to electric scooters. Then a calculation is carried out to determine the magnitude of the increase in mileage by comparing the maximum mileage of system 4 with the max mileage of system 1, system 2, and system 3. The data is recorded in Table 2.

Table 2. Large Increase in Maximum Mileage in System 4 Compared to Other Systems

	Maximum Mileage (km)	Maximum Mileage System 4 (km)	Increased Mileage
System 1	82.262		0.538%
System 2	79.473	82.705	4.066%
System 3	84.593		-2.231%

3.2 Testing The Effect Of Speed On Regenerative Backflow

Using a regenerative braking system with a 12.5% cycle, a test of the effect of speed on the magnitude of the regenerative backflow was carried out.

The armature current flowing from the motor is directly proportional to its speed. This can be observed from the graph of the comparison of armature currents between speeds to time in **Figure 2**.

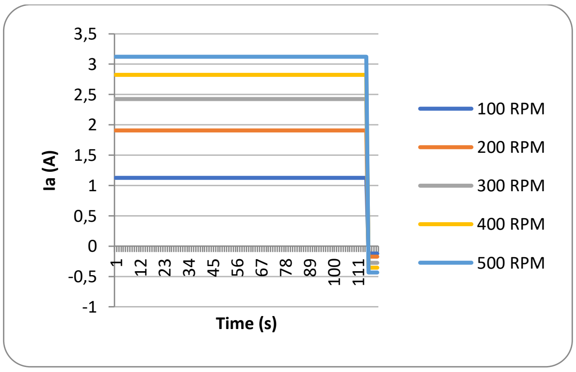

Fig 2. Comparison of Armature Currents Between Speeds Against Time

Although in the graph in Figure 2, it can be seen that there is a backflow, the current still cannot be used to charge the battery. By using a regenerative braking system, the current can be returned to charge the battery. The RMS value of the regenerative current that can be returned is apparently influenced by speed.

In Figure 3, you can see a comparison of the average results of three times the large testing of regenerative currents. To validate this experiment, a simulation of velocity variations was carried out and the amount of RMS regenerative current was measured as a comparison.

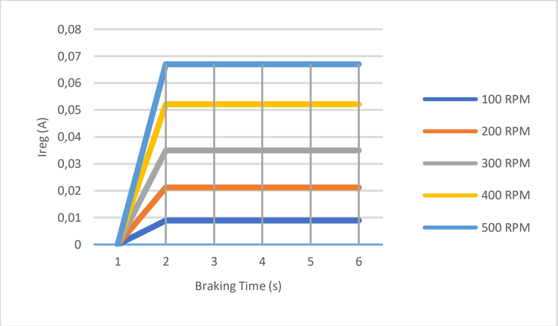

Fig 3. Comparison of Regenerative Currents Between Speeds Against Time

The data in figure 3 shows that the greater the angular velocity shortly before braking, the greater the magnitude of the regenerative current. This is due to the influence of the BEMF voltage on the magnitude of the regenerative current. The magnitude of the BEMF voltage can be obtained through equation 3 which shows that the magnitude of the BEMF voltage is affected by the angular velocity of the motor.

Based on this test, it is also known the cause of the fluctuations in the regenerative current generated in the previous test. Based on the previous chart, it can be seen that even though the desired speed is 500 RPM, there is still noise that makes the speed not always exactly 500 RPM. By knowing that the speed affects the armature voltage which affects the regenerative current, the speed that is not always the right 500 RPM is what causes there to be a difference in the results of the regenerative braking current obtained.

4 Conclusion

1. An electric scooter with a regenerative braking system is able to avoid danger by stopping the scooter's rate in less than 3 seconds by stopping the FGS-PI algorithm so that the motor speed response when braking is carried out immediately stops.
2. Electric scooters with a regenerative braking system are able to increase the mileage of the scooter by up to 4.066% when compared to electric scooters that only use a speed controller.
3. There are four quadrants that describe the operation of the motor, with the current value as the X-axis and the voltage value as its Y-axis. In this design, only operations are discussed in quadrant 1 (motoring) and quadrant 2 (braking).
4. The greater the angular speed of the motor, the greater the regenerative current that can be generated. In addition, the size of the duty cycle also determines the size of the regenerative current produced, the greater the duty cycle, the greater the regenerative current.

5 Suggestion

Based on the results of the design that has been carried out, there are several suggestions that can be done in the next design process, namely the duty cycle that regulates the regenerative backflow should be controlled according to the speed, duration of motoring, and armature current on the bike so that less energy is wasted into the outdoors and the braking process can also still be made smoother to increase the comfort of the rider using. In addition, to observe the magnitude of the regenerative current, a higher-resolution sensor is needed to clearly be visible at the magnitude of the current per point in time and less noise.

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