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Analysis of electric motor performance in micro mobility vehicles of Faculty of Engineering, University of Mataram

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ABSTRACT

Micro mobility electric vehicles require a small, efficient, and simple electric motor, but studies on the performance of low-voltage electric motors are still limited. This study aims to analyze the performance of a 12-volt BLDC motor applied to a two-wheeled electric vehicle for short-distance transportation. Tests were conducted at a rotational variation of 200–400 rpm with measurements of torque, output power, and energy consumption using a dynamometer. The results show that the BLDC motor produces a maximum torque of 2.94 Nm at 400 rpm with an average efficiency of 82% and an energy consumption of 0.15 Wh. These findings confirm that the 12-Volt BLDC motor is suitable for use as an alternative propulsion for light electric vehicles, especially in micro mobility systems that emphasize energy efficiency and design simplicity.

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1. INTRODUCTION

Micromobility is an increasingly attractive option, especially for short distances. Walking, cycling, and other modes of transport, such as e-scooters, are gaining popularity (Marques and Coelho, 2022; Ignaccolo et al., 2022). Furthermore, a new trend is emerging to introduce attractive products to the market that incorporate new/more sustainable materials to improve well-being (Mitroloulos et al., 2023). A significant issue in the micromobility nexus concerns understanding the needs of emerging transport devices and their environmental, social, and economic impacts, as well as sustainability (Weiss et al., 2020) within micromobility transport systems, particularly as they develop and implement new products, improve the safety and comfort of ergonomic personal mobility devices (PMDs) (Skuza and Jurecki, 2022; Wu et al., 2015), and ensure security and privacy as

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digitalization advances. This can raise awareness among policymakers and the public while providing impactful information for decision-makers. (Marques and Coelho, 2022)

Electric vehicles are a major concern for everyone right now. However, with the introduction of new regulations regarding emissions-based taxation schemes, it's possible that they could become commonplace in the next five or ten years. Electric vehicles are a form of mobility powered by electronic devices, such as electric motors, with the energy stored in batteries (Baghdad et al., 2013). They can come in various forms, including cars, motorcycles, and even personal bicycles and scooters, which can be used as transportation in certain areas (Abduljabbar et al., 2021, Bekiroglu and Esmer, 2023).

Micromobility is increasingly recognized as a promising mode of urban transportation, particularly due to its potential to reduce the use of private vehicles for short-distance trips and reduce energy consumption (Fotouhi et al., 2020; Plelecha, 2020). Despite valuable research contributions representing fundamental knowledge on this topic, the current body of research appears to be quite fragmented regarding the role of micromobility as a transformative solution for meeting sustainability outcomes in urban environments. (Abduljabbar et al., 2021)
Electric vehicles are a much more efficient option (Jiang et al., 2018) compared to conventional vehicles powered by internal combustion engines. They use less energy and emit no air pollution (Jatmikod et al., 2020; Hu et al., 2017). However, to maximize the use of electric vehicles, it is important to consider their energy consumption (Hendra et al., 2021). Electric vehicles can be an excellent choice if you want to reduce your dependence on fossil fuels (Badin et al., 2013).

The energy consumption of a vehicle is the amount of energy used in kilo Watt hours (kWh) or can also be expressed in kilo Joules, however, the term kWh is more commonly used in terms of measuring the energy consumption of a vehicle (Koengkan, et al, 2022). The energy capacity stored in an electric vehicle battery is usually expressed in kilowatt-hours so that the battery life can be easily calculated, as in general gasoline-fueled vehicles, fuel consumption is measured in liters/km (l/km) or gallons/miles (GPM) (Rodgers, et. al, 2014; Mediouni, et al., 2022).

2. RESEARCH METHODS

This research uses experiments to measure the parameters of electric current and the magnitude of the voltage difference in the electric vehicle circuit at various vehicle speed variations. In the preparation stage, supporting tools for this activity will be collected, such as measuring instruments (meters, rotational measuring instruments, speed measuring instruments, torque meters, current measuring instruments, voltage and battery power), welding machines, cutting grinders, drilling machines and lathes machines. These tools are available in the production laboratory of the Faculty of Engineering, University of Mataram.

During the design and assembly phase, the system will be designed based on the load and vehicle weight, thus determining the dimensions of the vehicle to be manufactured. Several vehicle stability parameters will also be considered during this design phase, including the distance between the front and rear axles (wheelbase), wheel camber, and motor installation to drive the vehicle. The assembly process will then be carried out according to the design.

At the stage of setting the vehicle drive system parameters, the position of the BLDC motor, chain and sprocket, battery placement, motor placement adjustments and adjustments to the vehicle's wheel drive axle will be adjusted. The final result of the design and manufacture of micro mobility looks like figure 1 below

Figure 1. Micro mobility research object.

The test system consists of a battery that stores energy by converting electrical energy into chemical energy and can release energy by converting chemical energy into electrical energy. The battery used is a lithium-ion phosphate (LiFePO4) type. A motor is a device that converts electrical energy from the battery into mechanical motion that drives the wheels. Motors operate on the principle of electromagnetism, where an electric current flowing through the motor coils produces a magnetic field that causes the motor rotor to rotate

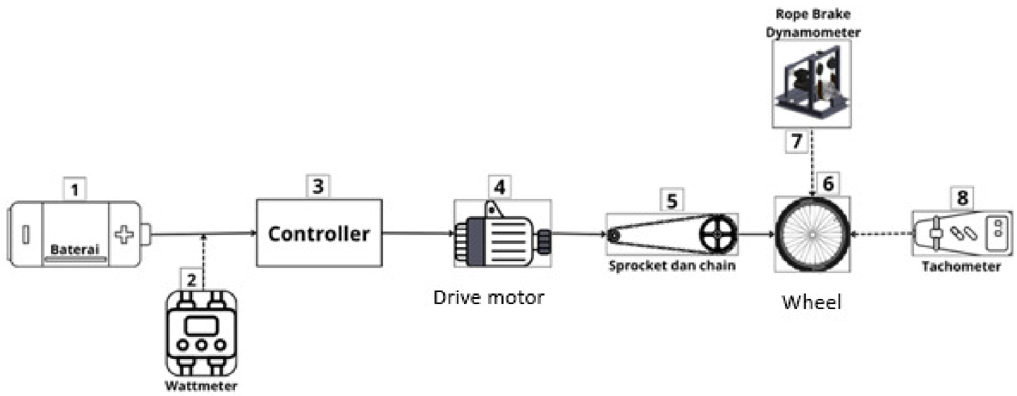

Figure 2. Test equipment scheme.1. baterray, 2. whattmeter, 3. controller, 4. Motor, 5. Sprocket and chain, 6. wheel, 7. Rope brake, 8. Tachometer.

Chain dan Sprocket (rantai dan roda gigi rantai) merupakan salah satu jenis transmisi. Chain dan sprocket berfungsi untuk menyalurkan transmisi gaya putar atau tenaga dari satu komponen mesin ke komponen lain. Controller adalah komponen elektronik yang mengatur aliran listrik dari baterai ke motor. Controller berfungsi mengendalikan kecepatan dan torsi motor berdasarkan input dari pengendara dan juga mengatur fungsi regeneratif saat pengereman untuk mengisi ulang baterai. A BLDC motor modified from an alternator was used in this study because of its advantages as a micromobility drive due to its high efficiency, long life, silent operation, and good durability. This optimal performance is supported by its brushless design, which reduces friction and wear, and the ability to precisely regulate speed via PWM.

3. RESULTS AND DISCUSSION

Based on the tests conducted at the Electric Car Workshop of the Faculty of Engineering, University of Mataram, this study tested the performance of a modified alternator as a driving motor. The tests were conducted by varying the rotation (rpm) of the motor, namely 200 rpm, 300 rpm, and 400 rpm. Each rpm variation was tested three times with observation parameters including electric voltage (Volt), electric current (Ampere), torque (Nm), time (second), power (Watt), and energy used (Wh). Observation data was obtained through direct measurement instruments that recorded changes in motor performance when used as a driving motor. The tests were conducted under environmental conditions and ambient temperatures that were considered constant.

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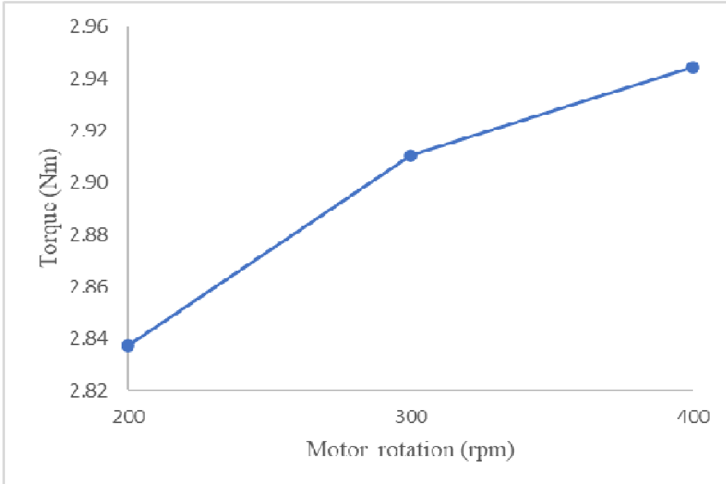


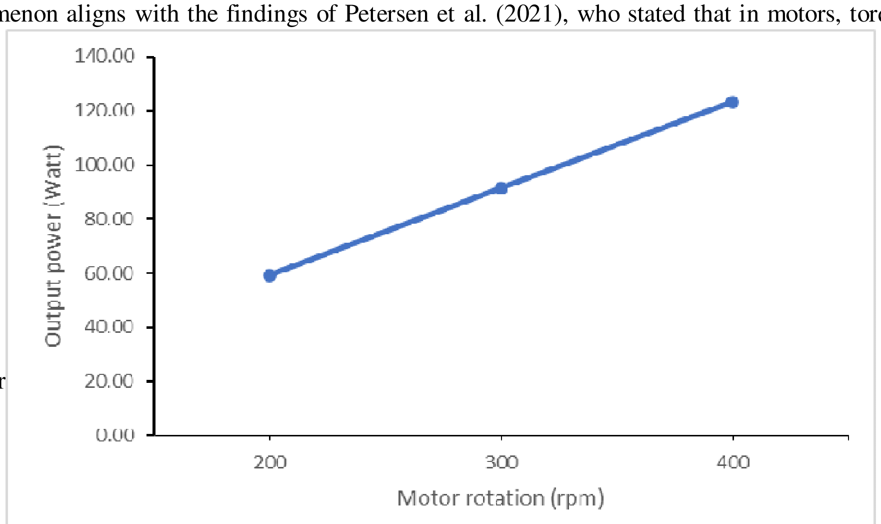
Figure 3. Relationship between motor torque and motor output shaft rotation.

Figure 3 shows the relationship between torque and motor rotation. It can be seen that the average value of torque produced by the motor. At a speed of 200 rpm the torque value produced is 2.84 Nm, then at 300 rpm it increases to 2.91 Nm. At low to medium speeds, motor torque increases although the increase is not too large, because the strengthening of the magnetic field and current in the rotor windings increases with increasing motor rotation speed. The increase in torque is still relatively small, but the motor continues to operate stably while starting to gradually improve mechanical performance, responsiveness, and energy efficiency. This situation shows that at low speeds the motor is still able to operate stably, with torque increasing with increasing rpm, but at this stage the efficiency of converting electrical energy to mechanical energy is still at an initial level and has not reached the optimal point, even though it has been subjected to a certain load.

However, when the rotational speed was increased to 400 rpm, a further increase in the achieved torque value was observed, reaching 2.94 Nm. This increase indicates that the higher the shaft rotational speed, the greater the electrical energy that can be converted into mechanical energy in the form of torque by the motor. This is closely related to the electromagnetic principle in electric motors, where the acceleration of the rotor rotation results in an increase in the interaction between the magnetic field and the electric current, resulting in a greater torsional force. This phenomenon confirms that the tested motor has the potential for higher performance when operated at higher rotational speeds, making its existence relevant for use as a driving motor in micromobility systems that require sufficient torsional power to support the vehicle load (Hieu et.al, 2023). Therefore, it can be concluded that in this test, the torque tends to increase consistently as the motor rotational speed increases, demonstrating the effectiveness of converting electrical energy into mechanical energy at high rotational speeds.

In the low to medium speed range, increasing the controller's PWM frequency directly increases the average voltage applied to the motor, thereby increasing the current flowing through the coils. Since BLDC motor torque is directly proportional to current, increasing current results in increased torque. In the 200–400 RPM range, the back-EMF effect is not yet large enough to significantly limit the current, so the system is still able to maintain or increase torque. The increase in torque with increasing RPM in this range is the result of the increase in effective voltage and motor current that are not yet hampered by the motor's electromagnetic characteristics at high speeds.

The test results in this study indicate that torque increases as motor speed increases up to a certain point. This phenomenon aligns with the findings of Petersen et al. (2021), who stated that in motors, torque increases



with engine speed until it reaches a maximum point, before decreasing at higher speeds. Although the drive mechanism in this study uses an alternator-based electric motor, this non-linear trend can still be used as a comparison to demonstrate that optimal rotational speed is required to produce maximum torque in various types of drive systems.

Figure 4. Relationship between average motor output power and motor output shaft rotation.

Based on Figure 4, the increase in effective power as the motor rotation increases is one of the main characteristics in the performance of electric motor systems, including alternators that function as 12V BLDC motors. The test results show that at a speed of 200 rpm, the effective power generated is 59.38 Watts. When the speed is increased to 300 rpm, the power increases significantly to 91.45 Watts, and at 400 rpm it reaches 123.34 Watts. This increase in power shows a direct relationship between rotational speed and the mechanical energy produced by the motor. The sharp increase in power indicates that in the motor, increasing rpm not only increases the rotational frequency of the motor shaft but also stimulates the work of the internal magnetic field to produce greater and more stable electrical energy, which is then converted back into mechanical energy in the form of shaft power.

This phenomenon is in accordance with the basic principle that the effective power in a motor is directly proportional to the torque and angular velocity, so that when the torque remains relatively constant or increases and the speed increases, the power output will also increase. With increasing rpm, the motor is able to draw a larger current and produce a stronger electromagnetic impulse, thereby improving the overall performance of the system. This indicates that the alternator has a more efficient performance at higher rpm, and is increasingly optimal in converting electrical energy into mechanical energy. From the perspective of micromobility applications, this increase in power is very important for vehicle acceleration and stability under real loads. Test results show that the alternator has a significantly increased performance in proportion to the rotational speed, with the highest efficiency at 400 rpm throughout the test that was carried out consistently and accurately.

This research aligns with the findings of Mahendra et al. (2024), who showed that increasing the rotational speed (rpm) of an electric motor directly affects the amount of mechanical power produced. The study found that mechanical power increases with increasing motor shaft rotational speed, as long as the torque produced remains proportional. This supports the focus of the research, which aims to evaluate the performance of the alternator as a motor based on variations in rpm, particularly in relation to torque, power, and energy. Thus, the relationship between rpm and mechanical power is an important aspect in understanding optimal motor performance, especially in systems that utilize BLDC motors as the drive motor.

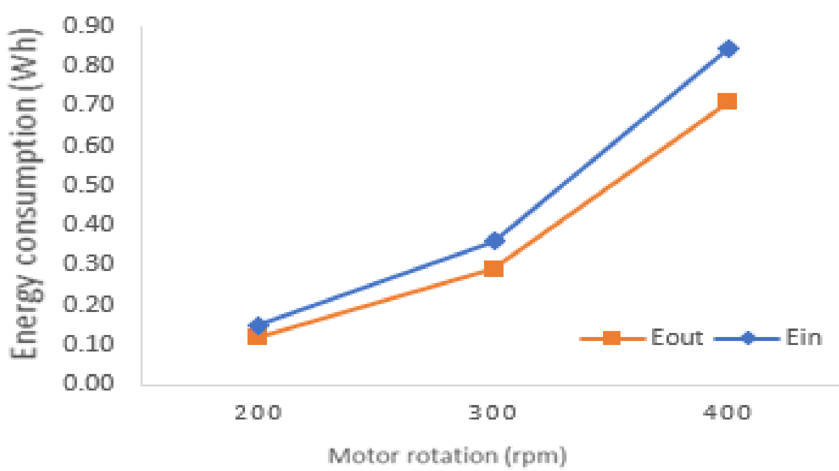


Figure 5. Relationship between electrical energy consumption and motor output shaft rotation

Based on Figure 5 which shows the energy consumption test results, it shows that the higher the motor rotation speed, the electrical energy required also increases quite significantly. At the lowest speed, namely 200 rpm, energy consumption was recorded at 0.15 Wh. When the speed is increased to 300 rpm, the energy used increases to 0.36 Wh, and at 400 rpm, this value increases again to 0.85 Wh. This spike in energy consumption reflects an increase in current requirements to maintain the motor working at higher speeds. In this DC motor system, a larger current will be required to generate additional electromagnetic force, which is responsible for

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keeping the speed and torque stable when the load is applied. The increase in energy required can also be attributed to the greater time duration and internal working force of the motor, which ultimately affects the amount of electrical energy consumed.

This demonstrates a close and progressive relationship between motor rotational speed and energy consumption. The higher the rotational speed, the higher the workload faced by the electromagnetic system in the alternator, thus requiring a greater energy supply. This needs to be understood as part of the basic characteristics of electric motors, where increasing speed typically requires increased current and power to maintain performance. However, this increase in energy consumption is offset by the increase in torque and output power, as explained in the previous discussion. This means that the alternator system used as a motor still demonstrates acceptable work efficiency in the context of micromobility. In other words, despite the increased energy demand, this is in line with the increase in overall motor output performance, making this system suitable for use in light electric vehicle scenarios.

This finding aligns with research conducted by Aryanto (2023), which showed a strong correlation between the level of electrical energy consumption and motor rotation speed. Increasing motor rotation speed generally results in an increase in the electrical energy required to maintain system operational stability at that speed. In other words, energy requirements are not solely influenced by workload but also depend heavily on speed and rotational speed. The faster the rotation, the more energy is used to maintain optimal performance.

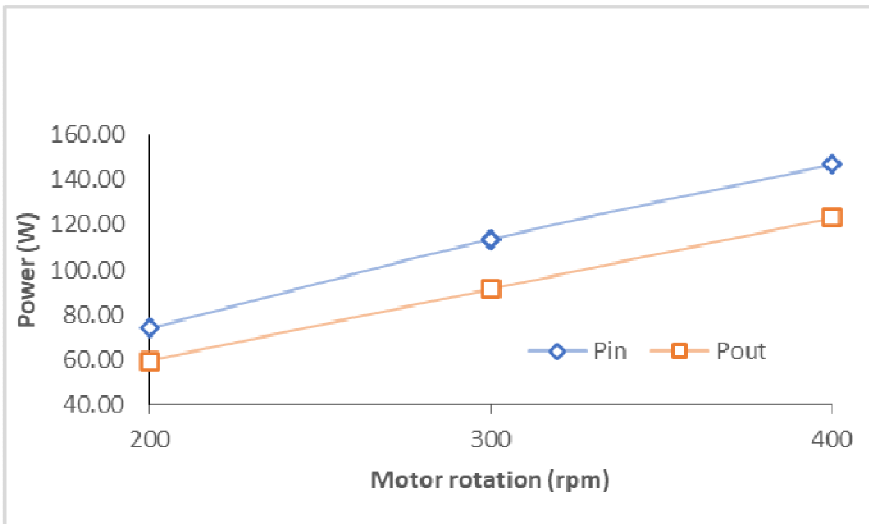

Figure 6. Relationship between motor input power and motor output at various motor speeds

As the motor speed increases from 200 to 400 rpm, both input and output power increase. However, the input power increases more than the output power. At higher speeds, the current increases, so resistive losses become more significant. Permanent magnet BLDC motors exhibit higher energy conversion efficiency compared to conventional DC motors. This is due to the elimination of excitation losses in the rotor, since the magnetic field is generated by permanent magnets, not electric current. However, the output power remains lower than the input power, in line with the law of conservation of energy. Energy losses in BLDC motors include resistive losses in the stator windings (copper losses), magnetic losses in the iron core (core losses), and mechanical losses such as friction and air resistance. Furthermore, the electronic control system also contributes to losses. In the low-speed range of 200–400 rpm, 12 Volt BLDC motors tend to exhibit lower output power than the input power because the motor's operating efficiency is not optimal. Under these conditions, some of the incoming electrical energy is used to overcome internal losses such as resistive losses in the coils, losses in the controller, and magnetic and mechanical losses such as friction and eddy current losses. In addition, to produce initial torque, the motor requires a large current, so the input power is higher than the output power.

4. CONCLUSION

From the results of the experiments that have been carried out, several findings have been obtained. Overall, the 12V BLDC system's drive motor demonstrates quite good performance in the context of micromobility vehicles. The BLDC electric motor is capable of producing increased torque and power at a given

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rpm while maintaining reasonable energy consumption. Therefore, the motor is suitable as an alternative drive motor for light electric vehicle applications, especially in systems that prioritize efficiency and simplicity.

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